NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN OBJECTIVE METHODOLOGY FOR ASSESSING CURRENT AND FUTURE TT&C ARCHITECTURES

by

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September, 1995

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY	2. REPORT DATE September 1995	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE AN OBJECTIVE METHODOLOGY FOR ASSESSING CURRENT AND FUTURE TT&C ARCHITECTURES	5. FUNDING NUMBERS
6. AUTHOR(S) Kruder, Todd G. Walker, Benjamin H. IV	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited.	

13. ABSTRACT

As DOD increases their reliance on space assets, a call for doing more for less has been initiated. Requests for more capability will present opportunities in technological advancements including methods for controlling those assets. Constrained by a reduced budget, the decision maker must be able to properly evaluate systems and select the best candidate. For Telemetry, Tracking, and Commanding (TT&C), the decision maker needs an objective methodology capable of aiding in the evaluation of TT&C systems. The thesis provides such an essential tool that will aid in the assessment of proposed TT&C architectures. The first section describes the process of TT&C by using activity modeling to describe the key functions and the present interrelationships among these key functions. To provide an initial basis of understanding, three current TT&C architectures were discussed: Air Force Satellite Control Network, Mission Control Center Johnson Space Center, and Naval Satellite Operations Center. This enabled the authors to highlight favorable trends utilized for enhancing performance. The thesis concludes with a demonstration of an objective methodology based on the Analytic Hierarchy Process. This approach resulted in the ability to provide a weighted ranking of proposed TT&C architectures and was illustrated using current architectures.

14. SUBJECT TERMS Air Force Satellite Control Network (AFSCN), Mission Control Center (MCC) Johnson Space Center, Naval Satellite Operations Center (NAVSOC)	15. NUMBER OF PAGES 133
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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AN OBJECTIVE METHODOLOGY FOR ASSESSING CURRENT AND FUTURE TT&C ARCHITECTURES

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY (SPACE SYSTEMS OPERATION)

from the

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ABSTRACT

As DOD increases their reliance on space assets, a call for doing more for less has been initiated. Requests for more capability will present opportunities in technological advancements including methods for controlling those assets. Constrained by a reduced budget, the decision maker must be able to properly evaluate systems and select the best candidate. For Telemetry, Tracking, and Commanding (TT&C), the decision maker needs an objective methodology capable of aiding in the evaluation of TT&C systems. The thesis provides such an essential tool that will aid in the assessment of proposed TT&C architectures. The first section describes the process of TT&C by using activity modeling to describe the key functions and the present interrelationships among these key functions. To provide an initial basis of understanding, three current TT&C architectures were discussed: Air Force Satellite Control Network, Mission Control Center Johnson Space Center, and Naval Satellite Operations Center. This enabled the authors to highlight favorable trends utilized for enhancing performance. The thesis concludes with a demonstration of an objective methodology based on the Analytic Hierarchy Process. This approach resulted in the ability to provide a weighted ranking of proposed TT&C architectures and was illustrated using current architectures.

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I. INTRODUCTION

A. PURPOSE OF THESIS

The purpose of this thesis is to present the decision maker with an objective methodology that can be used in determining the selection of a most favorable Telemetry, Tracking, and Commanding (TT&C) architecture. It has been observed that a need exists to integrate the current satellite control network in order to achieve a higher degree of efficiency. To do this, the decision maker requires four elements; a set of joint requirements, a system architecture, an implementation plan, and a cost operational effectiveness analysis (COEA). Currently, DOD lacks an adequate set of requirements, has no common system and therefore no implementation plan, and lastly lacks adequate information to put together an effective COEA. This thesis emphasizes identifying a generic TT&C system architecture and the development of a method to objectively compare two or more candidate architectures for future implementation.

B. METHODOLOGY

In order to better understand the problems associated with evaluating Telemetry Tracking and Commanding (TT&C) architectures, the major issues that effect TT&C systems will be discussed. Then, a discussion of a generic TT&C process will be examined followed by a description of three well known existing architectures, the Air Force Satellite Control Network (AFSCN), Mission Control Center (MCC), and Naval Satellite Operations Center (NAVSOC). Lastly, an objectively based scaling criteria is developed and presented along with an illustrated example using the AFSCN, MCC, and NAVSOC architectures to better clarify the concepts of the methodology.

C. SCOPE OF THESIS

The main focus of this thesis is to present a useful methodology for evaluating current and future TT&C architectures. A general discussion of issues that affect these

architectures will be given to characterize the environment. The thesis will only address those issues that affect generic TT&C systems. The objective methodology is presented along with an illustration using the AFSCN, MCC, and NAVSOC architectures as they exist at the time of this writing. As a result of the unavailability of actual values, all values associated with the illustration are chosen for illustrative purposes only.

D. BACKGROUND AND ISSUES SURROUNDING TT&C

Before proceeding, it is important that the reader have an understanding of the studies and publications currently effecting DOD Space agencies and TT&C architectural development. This brief background will provide the foundation for the rest of the material presented in this thesis.

1. Future Integrated TT&C Architecture Study

a. History

Early in 1993, Congress viewed satellite control as too costly and in January of 1994, the Joint Staff/J6 directed the United States Space Command (USSPACECOM) to lead in the development of the Future Integrated TT&C Architecture Study (FITAS). About the same time, the General Accounting Office (GAO) requested the use of the FITAS to aid in the evaluation of the Fiscal Year (FY) 96 Appropriations.

b. Purpose

Originally USSPACECOM was directed to do the following: (1) develop a comprehensive architecture and roadmap for an integrated DOD satellite control infrastructure; and, (2) reassess the Office of the Secretary of Defense (OSD) policy for application of MIL-STD-1582C, Satellite Data Link Standard: Uplinks and Downlinks.

However, in a counter proposal accepted by the Director Joint Staff, USSPACECOM opted to emphasize interagency ties first, then to address high level system features with the increased economy of making resources accessible for sharing across all participating agencies as a goal. [Ref. 1]

In order to accomplish this task five panels were organized and supervised by a Senior Steering Group (SSG). Each of the panels addressed one of the following: Requirements, Current Status, Evaluation Criteria, Fusion, and Implementation.

c. Summary of Findings

Findings from the FITAS revealed several factors, some of which will be discussed here. It was determined that the existence of a central authority to develop interagency satellite control guidelines was not readily accessible. The lack of mutual interagency interaction and a means to establish satellite control changes across the organizations needs to be examined. In a related issue, it was determined that organizations have evolved their own set of requirements and that benefits may lie in the development of universal requirements. The complexity of the Air Force Satellite Control Network (AFSCN) software maintenance program and their manpower intensive approach to satellite control was also addressed. For a complete discussion on the FITAS findings see Reference 1. [Ref. 1]

d. Conclusions

The completion of the FITAS touched on ten key concepts which involved the development of a long-term integrated DOD satellite control architecture and increased interagency satellite resource sharing. The ten concepts discussed are: (1) Management Structure, (2) First Plug-N-Use Tier, (3) Second Plug-N-Use Tier, (4) S-Band Exclusive Use of the Second Plug-N-Use Tier, (5) Use of In-Band commanding, (6) Frequency allocation issues, (7) Wave form or frequency changes, (8) AFSCN transition to distributed processing, (9) Manning reductions, (10) MIL-STD-1582C. The authors have decided to present those concepts most pertinent to the development of this thesis.

(1) First Plug-N-Use Tier: An initial overall effort to make common TT&C functions of individual systems accessible. The first tier is intended to permit all Defense Satellite Control Network (DSCN) nodes to produce and receive mutually understandable and useful information for all DSCN services. [Ref. 1]

(2) Second Plug-N-Use Tier: Intended for TT&C and mission data operations that will need to plug into the evolving Defense or National Information Infrastructure (NII) wherever possible for economy of scale and access to all other DSCN nodes. New systems , and those undergoing upgrades, will be required to conform immediately. International commercial standards will be used to the maximum extent possible. [Ref. 1]

(3) AFSCN transition to distributed processing. The AFSCN must transition to object oriented, distributed processing. To capitalize on reduced software development costs and software that already exists or is being developed for TT&C, communications, scheduling, and so on. [Ref. 1]

(4) Manning reductions. Reduction in On-Console, Communication, and Real-time Engineering Support. On console manning could be reduced by up to 33%. Communication manning could be reduced by up to 45%. Real-time engineering support for trend monitoring and anomaly resolution could also be greatly reduced. [Ref. 1]

2. Objective Technical Architecture Overview

a. History

The Objective Technical Architecture (OTA) was established to ensure both the North American Defense Command (NORAD) and USSPACECOM remain a viable force structure. The operational requirements document (ORD) was designed to provide the needed guidance in the acquisition of advanced technology and infuse that technology into NORAD and USSPACECOM Integrated Command and Control System.

By definition the OTA describes a minimal set of rules governing the arrangement, interaction, and interdependence of the parts or elements that together may be used to form an information system, and whose purpose is to ensure that a conformant system satisfies a specified set of requirements. [Ref. 2]

The OTA is divided into five sections; (1) purpose, background, and scope; (2) the Elements of NORAD / USSPACECOM OTA and infrastructure; (3) identification of a set of standards guidance profiles based on OTA - Technical Reference Model (OTA TRM); (4) explanation of the management approach for the OTA; (5) examples of how to use the OTA within the acquisition of information systems. [Ref. 2]

b. Purpose

The OTA is designed to provide guidance while defining, designing, and developing those systems that will become a part of NORAD and USSPACECOM Integrated Command and Control System. In addition, the OTA provides guidance to agencies and staffs that are involved in the directing and managing modifications of existing NORAD / USSPACECOM systems. Lastly, the OTA guides those involved in the testing, integrating, certifying, and training or maintaining new systems or modified systems. [Ref. 2]

It should be noted that the OTA applies to NORAD, USSPACECOM, Air Force Space Command (AFSPC), United States Army Space Command (USARSPACE), Naval Space Command (NAVSPACECOM), Canada, and the United Kingdom. While the guidance contained within the OTA applies to all those involved in requirements definition and analysis. [Ref. 2]

c. Summary of Findings

For the purpose of this thesis, the authors will summarize sections two and three which covers both elements and standards. The Command, Control, Communications, Computer and Intelligence for the Warrior (C4IFTW) tenants provide the bases for the OTA operating perspective. The eight tenants of C4IFTW are expounded on within the OTA and are listed here for simplicity; 100 % interoperability, Common Operating Environment (COE), Flexible modular C4I packages, Horizontal and vertical C2, CINC pull on demand, Real - time decision aiding, Global resource management and control, and Seamless operations.

Along with the above tenants, the OTA emphasizes a set of design and development principles that aid in broadening the development of mission requirements that include configuration management, testing and certification, training and simulation, security, reliability, maintainability, robustness, business processes and data standardization.

Consistent with the direction from the William Perry letter, Specifications & Standards -- A New Way of Doing Business, dated 29 June 1994, the OTA standards guidance reflects the standards currently used in existing operational systems and / or systems currently being developed. [Ref. 2]

The OTA standards guidance stresses the importance of migrating to open systems and provides four types of performance-based criteria: commercial item descriptions (CIDs), guide specifications, standard performance specifications, and

program peculiar specifications. These specifications would develop into standards for use in future systems. The criteria to achieve this appears throughout the OTA guidance profiles. [Ref. 2]

3. DOD Technical Architecture Framework for Information Management

a. History

The Technical Architecture Framework for Information Management (TAFIM) provides guidance necessary to establish a DOD wide framework required to manage multiple technical architecture initiatives. The TAFIM is intended to influence three areas: the use of common principles, assumptions, terminology in DOD Component (Services, Agencies, and CINCs) technical architectures; the definition of a single structure for the DOD technical infrastructure components (system components) and how they are managed; and the development of information systems in accordance with common principles to permit DOD wide integration and interoperability. [Ref. 3]

b. Purpose

The TAFIM provides guidance for the evolution of the DOD technical infrastructure by focusing on the following: services, standards, design concepts, components and configurations. These elements guide the development of technical architectures to meet specific mission requirements. It should be pointed out that the TAFIM does not provide a specific system architecture. [Ref. 3]

Important to architecture design, the TAFIM introduces concepts such as interoperability, portability, and scalability of DOD information systems. The TAFIM assumes that information systems will and must interoperate at some time. [Ref. 3]

With proper implementation, the TAFIM guidance should achieve the following results: promote integration, interoperability, modularity, and flexibility; guide acquisition and reuse; and speed delivery of information technology and lower its costs. [Ref. 3]

The TAFIM is divided into eight volumes that represent the varying states of development and maturity: (1) Overview, (2) Technical Reference Model, (3) Architecture Concepts and Design Guidance, (4) Implementation Manual, (5) Support Plan, (6) DOD Goal Security Architecture, (7) Standards Profile and Implementation Guidance, and (8) DOD Human Computer Interface (HCI) Style Guide. [Ref. 3]

Of particular importance to this thesis is Volume 3, Architecture Concepts and Design Guidance. Volume 3 provides concepts and design guidance that will help architects, integrators, and system designers to develop information systems technical architectures and are considered in the context of the Technical Reference Model found in Volume 2. The key elements found in this volume are in the following section. [Ref. 4]

c. Summary of Findings

Volume 3 of the TAFIM series describes several models in varying degrees of detail. These models include: the Architecture Models, Client / Server Models, Host-Based Models, Master-Slave and Three-Tiered Models, Peer-to-Peer Models,

Distributed Object Management Models, Database Management Systems (DBMS) and Data Models. [Ref. 4]

The volume also defines several key elements involved in developing information architectures such as Data Security. Data security includes measures that are implemented to prevent unauthorized access, modification, use, and dissemination of data stored or processed by a computer system. Data security also includes data integrity, and protecting the system from physical harm.

The Open System Interconnection (OSI) Reference Model is used for data communications in the TAFIM. The model consists of the following seven layers: (1) physical layer, (2) data link, (3) network, (4) transport, (5) session, (6) presentation, and (7) application. The seven layers are structured to facilitate independent development within each layer and to provide for changes independent of other layers. [Ref. 4]

Lastly, the volume provides an overall Design Guidance for use by all developers of information systems. The following are guidelines for designing specific architectures;

- An architecture will contain components to implement only those reference model services that it requires. [Ref. 4]

- Components may implement one, more than one, or only part of a service identified in the reference model. [Ref. 4]

- The components should conform to the profile standards that are relevant to the services they do implement. [Ref. 4]

E. OUTLINE OF CHAPTERS

1. Chapter II. Defining the Core TT&C Elements

In this chapter, a description of a generic TT&C system is provided to aid the decision maker in understanding the process involved. To achieve this, the most basic elements in the area of telemetry, tracking, and commanding are defined. A discussion on the primary functions and their relationship between one another is conducted. The relationships identified in the TT&C process are further illustrated through graphic modeling.

2. Chapter III. Current Methods and Trends

In this chapter, the authors present a background on three well known U.S. TT&C facilities utilized by the DOD: Air Force Satellite Control Network (AFSCN), Mission Control Center (MCC), and the Naval Satellite Operations Center (NAVSOC). The background includes a look at the historical development, command structure, personnel, and operational methodology used by each facility. The trends in TT&C architectures are then highlighted and are used as an aid in the formulation of the comparison methodology.

3. Chapter IV. Comparison Methodology

In this chapter, the actual technique for comparison is presented. The process presented is an objective approach that is intended to be a useful step by step methodology that will produce valuable information for the decision maker about which candidate architecture should be selected amongst a number of alternatives. Each step is

illustrated in an example conducted using the AFSCN, MCC, and NAVSOC architectures.

4. Chapter V. Conclusions and Recommendations

As stated in its title, this chapter will provide a summary that highlights essential ideas discussed and recommend areas of further study.

II. DEFINING THE CORE TT&C ELEMENTS

A. INTRODUCTION

Although there exist numerous sources concerning TT&C, there has been little or no work done in attempting to analyze the process of conducting TT&C. The primary reason for understanding this process is to ensure TT&C is conducted as effectively and efficiently as possible. Secondly, it will provide the decision makers a more through understanding of this process to enable them to make sound judgmental choices in the procurement of future systems. This is accomplished by providing a basic definition of TT&C, identification and mapping of functional areas, and lastly the identification of common system drivers. This chapter will provide the above aids to the decision maker and will be used in subsequent chapters to examine the overall TT&C process and its associated measures of performances (MOPs) and measures of effectiveness (MOEs).

B. DESCRIPTION OF A GENERIC TT&C ARCHITECTURE

As the name implies, the most fundamental functions of TT&C are telemetry, tracking, and commanding. In order to utilize a space vehicle (SV) one must first be able to locate it and then track it. Next, one must be able to communicate with it and command the SV to carry out its functions. Lastly, one must be able to obtain data (telemetry) from the SV.

1. Telemetry

The telemetry of a SV consists of measurements taken onboard by the SV sensors and then transmitted to either a ground facility or spaceborne receiver. The two basic types of telemetry are analog or digital. The most common forms are:

- High-Level Analog

  A telemetry channel with information encoded as an analog voltage. These are active analog inputs in that the command and data handling system does not provide measurement excitation. Data handling

equipment converts this information to digital form.
[Ref. 5]

- Low-Level Analog

A telemetry channel with information encoded as an analog voltage. The signal range is such that amplification is needed before the information is encoded into digital form. [Ref. 5]

- Passive Analog

A telemetry channel with information encoded as a resistance. The command and data handling system supplies a constant current to the resistive sensor and encodes the resulting IR voltage drop into a digital word. [Ref. 5]

- Bi-Level (Discrete) Input

A telemetry channel conveying two state information (such as on/off or enable/disable). Information is encoded as voltages, but may be encoded as a resistance or presence or absence of a signal. [Ref. 5]

- Serial Telemetry (Digital) Interface

A 3-signal interface used to transfer digital data from an external source to the data handling equipment. The command and data handling system provides a shift clock and an interface enable signal to control data transfer. [Ref. 5]

Telemetry is essential because it establishes a communication path downlink from the SV to the ground station. This allows the ground station to receive health and status of the SV which would include some of the following: voltages, currents, and temperatures. In addition, mission/payload related data would be downlinked to the ground station to be later processed and disseminated to the user.

2. Tracking

Space vehicle tracking involves locating a specific SV and then following its movement through space as a function of time. The position of the SV as a function of

time is determined by the use of the following measurements: elevation, azimuth, range, and range rate. Once the SV is acquired, the ground station can then point the receiving antenna at the SV to receive the telemetry data. Once the ground station begins to receive the telemetry, most antennas will automatically track the acquired SV maintaining maximum signal strength. [Ref. 6]

3. Commanding

Commanding is the method of controlling the SV from the ground while in line-of-sight of a ground station. SV commanding is important for many reasons. Commands transmitted to a satellite turn on or off such things as thrusters, sensors, recorders, etc. SV commands may also accomplish an attitude maneuver or an orbital adjustment maneuver.

The four primary methods of transmitting commands are single, block, repetitive, and timed-repetitive. Single command is the transmission of a single command word. Block command is a group of single commands represented by just one command number. A repetitive command is a single or block command that a ground station retransmits continuously until there is a command verification or a selected number of transmission attempts have been reached. The timed-repetitive command is the transmission of a block or single command for a given period of time (it is the least frequently used method). [Ref. 6]

4. Ground System Basic Elements

The ground system of a TT&C architecture can be described using eight elements:

- Antenna System

This includes a single antenna and mount, its associated actuators, consoles and servo circuitry that control the antenna, the feeds and transmission lines that carry the radio frequency (RF) signal to and from the equipment. [Ref. 5]

- Autotracking

The use of a received space vehicle signal to steer the antenna. [Ref. 5]

- Receive RF Equipment

The equipment required to accept the downlink carrier frequency from the antenna system, down-convert it to intermediate frequency, and demodulate it to a base band signal for the equipment devoted to mission data recovery and TT&C. [Ref. 5]

- Transmit RF Equipment

The equipment required to accept tracking and command signals from the ground systems TT&C component and modulate them onto the RF uplink which it also generates. [Ref. 5]

- Mission Data Recovery Equipment

Equipment required to condition the mission data before relaying it to data users and ground system components. [Ref. 5]

- Data User Interface

Equipment required to connect the mission data recovery equipment and the data user. [Ref. 5]

- TT&C Equipment

Equipment required to condition and distribute received telemetry and tracking signals. Also it electrically formats, authenticates, and time-tags transmitted command and tracking signals. [Ref. 5]

- Station Control Center

This center is given the responsibility to control the configuration of, and the interconnections between, the ground station components. Operating under instructions from the ground system's mission control center, it keeps the ground station configured to support mission operations. [Ref. 5]

- Mission Control Center

This center plans and operates the entire space mission, including the configuration and scheduling of resources for both space and ground system. It computes and issues information needed by ground system elements and data users, such as data on the spacecraft's orbit, ground station pass times, and antenna pointing angles. [Ref. 5]

C. IDENTIFICATION OF TT&C FUNCTIONS

1. Introduction

This section will develop a common description of TT&C related functions and illustrate their interrelationship within the TT&C process. To accomplish this, a three level approach is used. This approach classifies a function into one of three levels: Primary, Secondary, and Sub-Function. To explicate this approach, the DOD descriptive language $IDEF_0$ is used. In particular, Design/IDEF (version 3.5) developed by Meta software corporation was the tool selected. It will be noted that in this chapter only the analysis and design diagrams for the higher level activities will appear. The complete set of $IDEF_0$ illustrations developed for this architecture, with all inputs and outputs included is located in Appendix A. $IDEF_0$ requires the user to define the functions associated Input, Output, Control, and Mechanisms. These four elements will be highlighted in the following sub-sections; and a complete definition of the elements is contained in Appendix B.

2. Primary Functions and Associated Secondary Functions

The upper levels of the $IDEF_0$ diagrams provide a method to display the importance of certain key functions which the authors have identified as primary functions required to conduct TT&C. Corresponding secondary functions will be identified but later discussed in the following section.

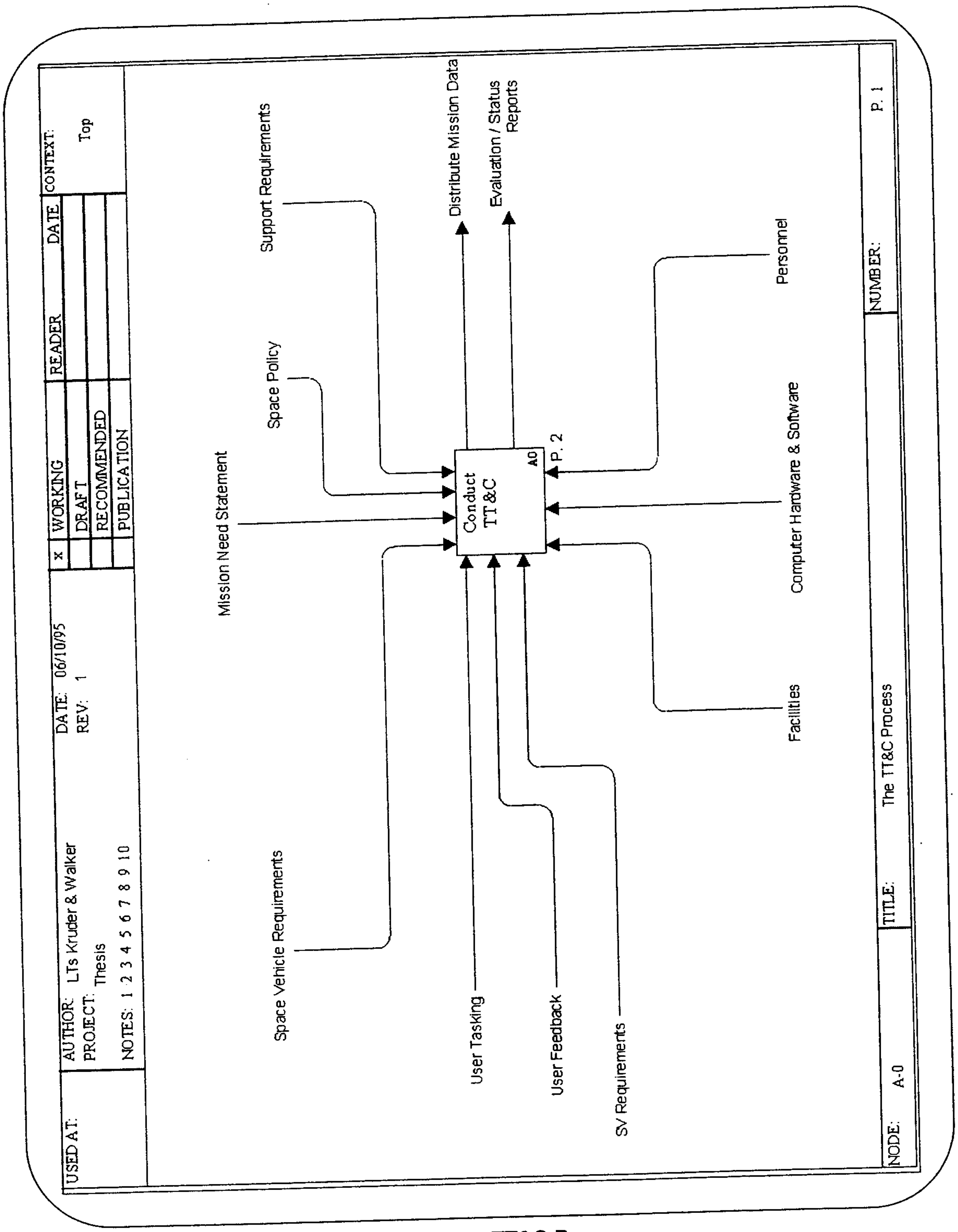


Figure 1, The TT&C Process

Figure 1, The TT&C Process, illustrates the Top level of the TT&C process. This diagram shows all the inputs, outputs, controls, and mechanisms associated with the top level. The essential components, both required for and result of the process, were identified and placed on the top level diagram indicating their contribution.

At the top of the figure, the four major controlling factors are listed: Space Vehicle Requirements, Mission Need Statement, Space Policy, and Support Requirements. These controls tend to highlight the long term requirements pertaining to the overall role or mission of a space vehicle and ensuring its health over time. They are used to establish doctrine, policies, and standard operating procedures (SOP) necessary for the proper utilization of any space asset.

Located on the left are the inputs to the TT&C process: User Tasking, User Feedback, and Space Vehicle (SV) Requirements. Basically, inputs act as the initial starting mechanism to the process. They are a response to a need that must be fulfilled in the short term unlike controls which involve long term concerns. The user places the process into motion by providing a task to a controlling authority of a military space asset or in stating recommendations concerning outcomes of previous tasking. These methods are known as User Tasking and User Feedback, respectfully. It is important to note that Space Vehicle Requirements acts as both a control and an input. During the design of a space vehicle, specific handling methods and limitations are incorporated to provide as long a life as possible. However, as a system reacts to its environment, unforeseen abnormalities tend to occur and must be corrected or compensated for in the short term to avoid damage or loss of the space vehicle.

Listed at the bottom of the diagram are the three primary resources which aid in supporting the process of conducting TT&C. Facilities provide the structures which house the Computer Hardware & Software elements and their operators and maintainers known as Personnel.

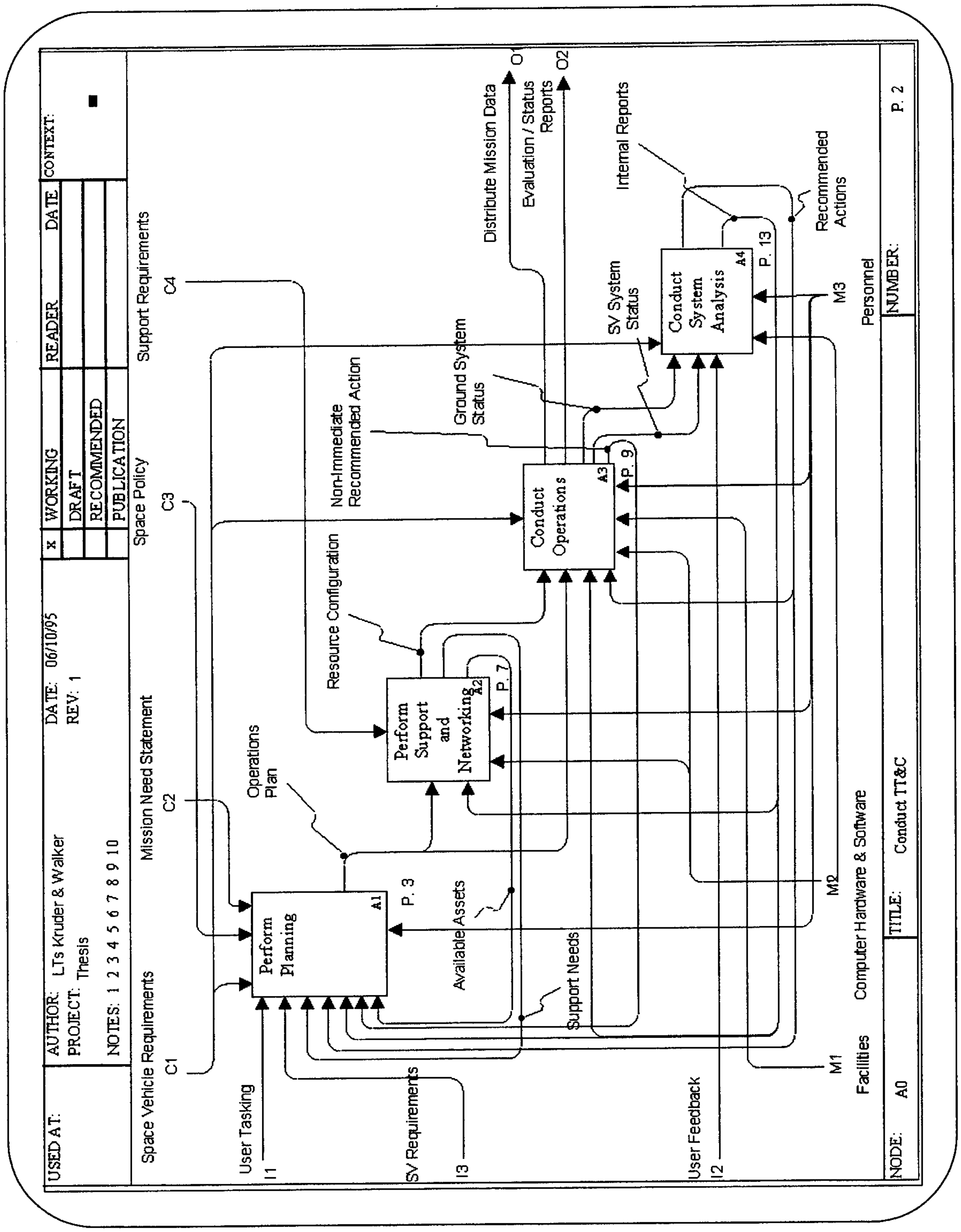


Figure 2, Conduct TT&C Primary Functions

The desired results of this process are Evaluation / Status reports concerning the system and mission data requested by the user which initiates User Feedback. This is simply a broad look at the TT&C process. Further understanding of the process is provided within the next level diagrams.

Figure 2, Conduct TT&C Primary Functions, illustrates the four primary functions required to conducting TT&C. They are characterized as the following: Perform Planning, Perform Support & Networking, Conduct Operations, and Conduct System Analysis. The $IDEF_0$ diagram illustrates the interrelationship of those four key functions. It is able to accomplish this by highlighting the dominating outputs of each function and mapping them as inputs to the others.

An overview of the process shows initially that it begins with a planning stage. User tasking, in conjunction with available assets, SV requirements, governing policies, and other initial requests, allows the creation of an operational plan. This plan becomes essential in identifying and ensuring the proper configuration of resources and prioritizing of assigned missions. Throughout the process a continuous planning cycle is achieved by maintaining feedback loops between the functions which allows for modification and improvement to the original operations plan.

The next stage, Perform Support and Networking, involves coordination of all required assets, which includes items such as remote antenna sites, computer workstations and their operators. The proper execution of the plan is assured by developing a specific resource configuration which will be utilized by the personnel involved in the conducting of actual operations. Feedback to the planning stage is in the form of listing available assets and stating needs for continued support capability such as personnel training and scheduling down time for required maintenance.

The main purpose outlined in this process is to produce results for the user. These results are derived from the third stage, Conduct Operations, in the forms of user requested mission data to support military operations or reports to superiors which detail current status and efficiency of the TT&C facility.

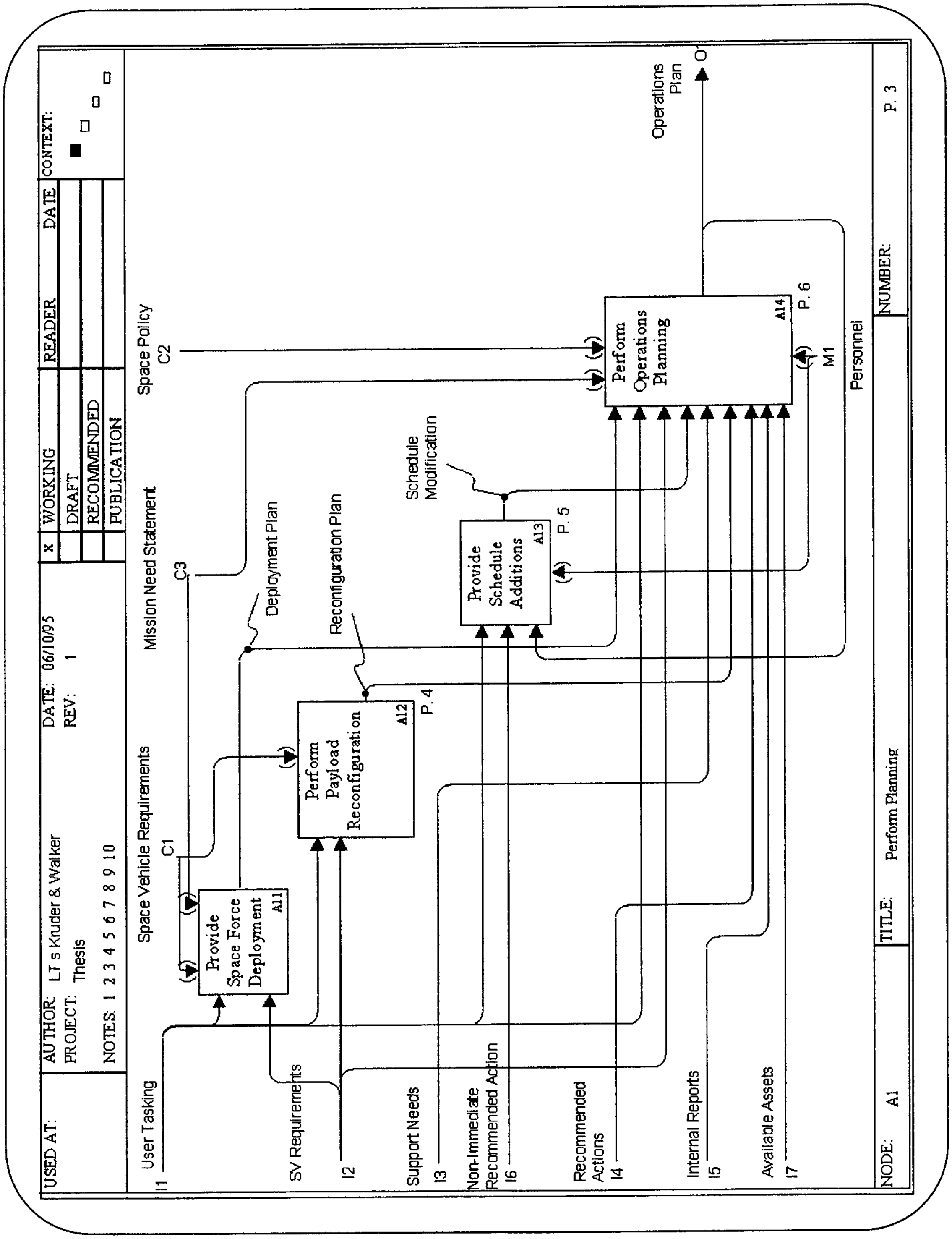


Figure 3, Perform Planning

Outputs, that remain internal to the process at this level, were non-immediate recommended actions which would be placed in the operations plan to ensure the continued health of the space vehicle and status of both the SV and ground facility required for system evaluation.

It is important to note that the final stage is not simply delivery of mission data to the user. There exists an internal method of analyzing the complete process through the use of reports, evaluations, and recommendations which allows for system improvements. Conduct System Analysis is the last of the primary functions detailed in the $IDEF_0$ diagram. It includes internal feedback to the other functions in an effort to achieve the most efficient mode of operation. Recommended Actions are outputs of this stage which attempt to rectify abnormalities identified in the system.

In the concluding part of this section, the next level of each primary function is diagrammed and discussed. The functions which support any given primary function are known as secondary functions. These functions are listed in the following sub-sections with their associated primary function; however, the secondary function definitions are all located in Section C.3 of this chapter.

a. Perform Planning

This primary function involves the correlation of multiple inputs, identifies potential options and presents a final strategy which is then reintroduced into the system and accomplished over a period of time. The $IDEF_0$ diagram for this function appears in Figure 3, Perform Planning.

<u>ASSOCIATED SECONDARY FUNCTIONS</u>

- Provide Space Force Deployment
- Perform Payload Reconfiguration
- Provide Schedule Addition
- Perform Operations Planning

These next level functions were determined to be the major parts of the TT&C Planning process. As stated earlier, the goal of this primary function was the creation of the Operations Plan. This plan is identified as a master schedule which outlines what needs to be done to a SV, how it will be done, and who, with what resources, will do it. To develop this plan, a series of minor plans are formulated and merged along with inputed recommended actions. The driving force behind prioritizing mission related actions is user tasking and SV requirements. Perform Operations Planning accomplishes this task by acting as the main merging function. It is here that the routine schedule for SV monitoring and mission tasking occurs based on support needs, available assets and standard operating procedures. A continual loop for changes to the plan are provided for with the input, Schedule Modification. Based on needs which must be acted upon in the short term, Provide Schedule Additions becomes the avenue for the user and others within the system to work into the schedule critical modifications. Finally, it was determined that the functions Provide Space Force Deployment and Perform Payload Reconfiguration were aspects of the TT&C process that required special handling above what would normally be known as routine activities. Their output would be the drafting of a deployment plan and reconfiguration plan, respectfully, which would be merged with the routine plan. Once again, this allows for the creation of a prioritized schedule known as the Operations Plan which directly impacts both conducting operations, and support and networking arrangements.

b. Perform Support and Networking Functions

Once the Operations Plan has been formulated, it is the primary task of the Perform Support and Networking function to ensure availability of required assets and resources. The primary output is the establishment of a Resource Configuration. The ability to assign control and authority of individual assets provides the foundation necessary to link all other functions to their required resources in an effort to support all aspects of a TT&C system. The supporting secondary functions are listed below and their interrelationship is displayed in Figure 4, Perform Support and Networking.

ASSOCIATED SECONDARY FUNCTIONS

- Conduct Training
- Conduct Logistics
- Conduct Maintenance
- Allocate Resources

The operations plan is seen as the input which schedules certain non-operational activities to commence. This plan is further supported by internal reports which outline additional concerns surrounding those activities. These activities include scheduling simulator time for operators or allowing them time to attend training courses to provide improved performance. This involves the function known as Conduct Training. As these training opportunities are conducted, feedback concerning the outcome of these activities begins with the delivery of personnel qualification status updates. Qualified personnel are counted on the available assets report while deficiencies are highlighted in the support needs report. Both of these reports eventually arrive back at the planning stage to start the process all over again.

Conduct Maintenance works along the same lines as that of the function, Conduct Training. The main difference is the scheduling of hardware and software components vice personnel activities. It is important to provide down time for maintenance work, but doing so removes an asset from use for a period of time.

Maintenance work ensures the continued health of a given TT&C resource and as such must be scheduled for by the planners. The feedback to the planners begins with the maintenance status report which is sent to be added to both the support needs and available assets reports.

The logistic schedule is the result of the function, Conduct Logistics. After reviewing inputs to the function, non-flight essential support needs are identified and a plan of action is drafted. This logistic schedule states activities that are occurring to assure delivery of determined support needs.

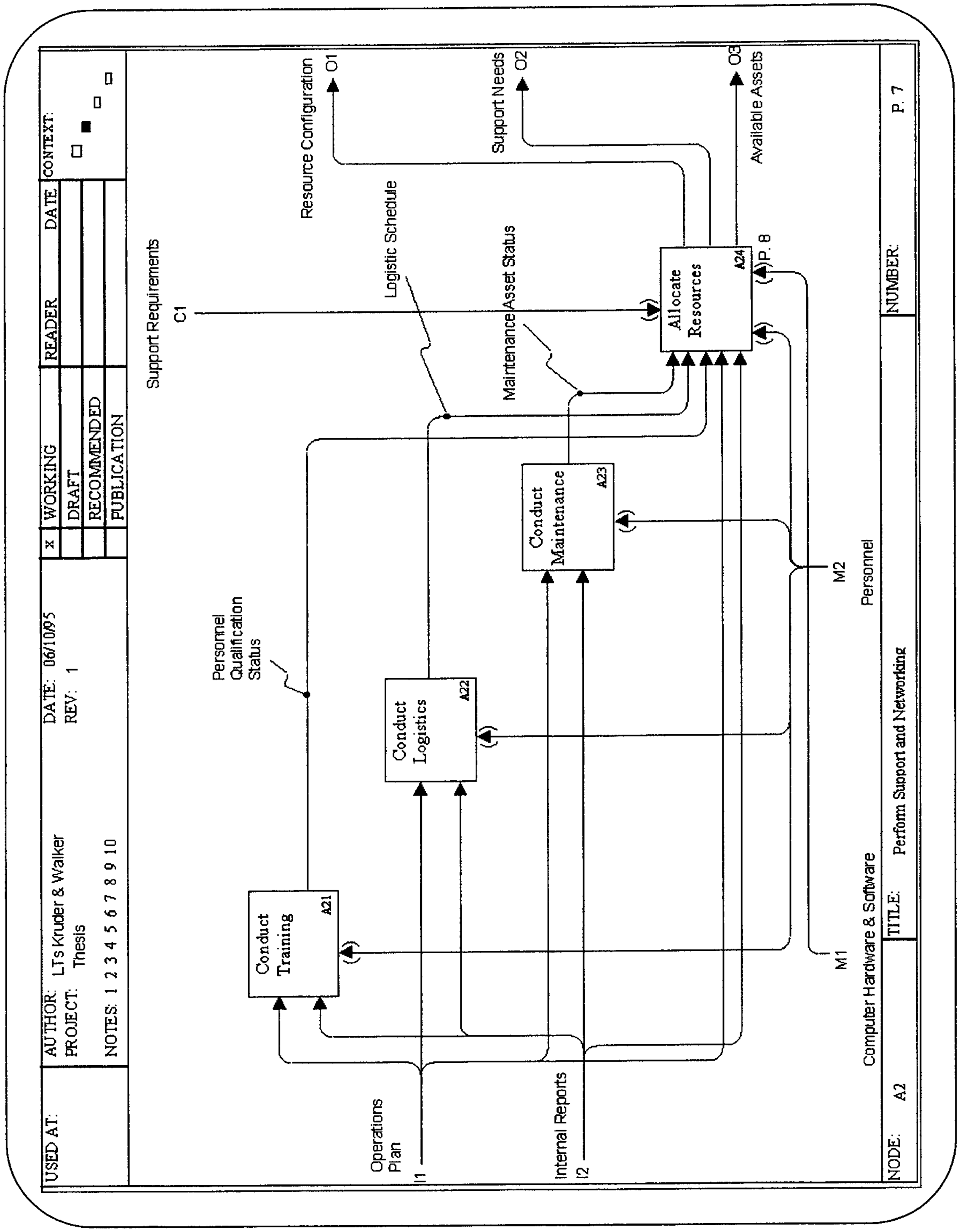


Figure 4, Perform Support and Networking

The final stage for merging all the above information is called Allocate Resources. Controlled by standardized support requirements, this function takes all inputs and interprets resource needs. Conflicts in resource assignment are handled through the prioritization of missions established in the operations plan. As previously stated, the configuration of resources is the focus of this primary function. This output greatly affects how smoothly operations will be conducted.

Although not shown in the diagram, the primary function, Perform Support and Networking, provides the additional foundation for Communication Connectivity and Security. Communication Connectivity is the ability to provide secure primary and alternative communication links that would connect control centers, remote ground facilities, and external users / facilities. Connectivity would be comprised of the following: LAN / WANs, data link terminals, commercial services, military communication satellite, and domestic commercial communication satellites. Security is the ability to protect against those threats identified in DOD Command & Control Warfare (C2W) / Information Warfare (IW) assessment documents. Security capabilities shall encompass the following: system, personnel, information, physical, communications, emanations, and computer systems.

c. Conduct Operations

The Conduct Operations function is responsible for the execution of the operations plan. The associated secondary functions are listed below and a graphical representation is given in Figure 5, Conduct Operations.

<u>ASSOCIATED SECONDARY FUNCTIONS</u>

- Provide Space Vehicle Position and Orientation Management
- Perform Constellation Management
- Execute TT&C
- Disseminate Mission Data

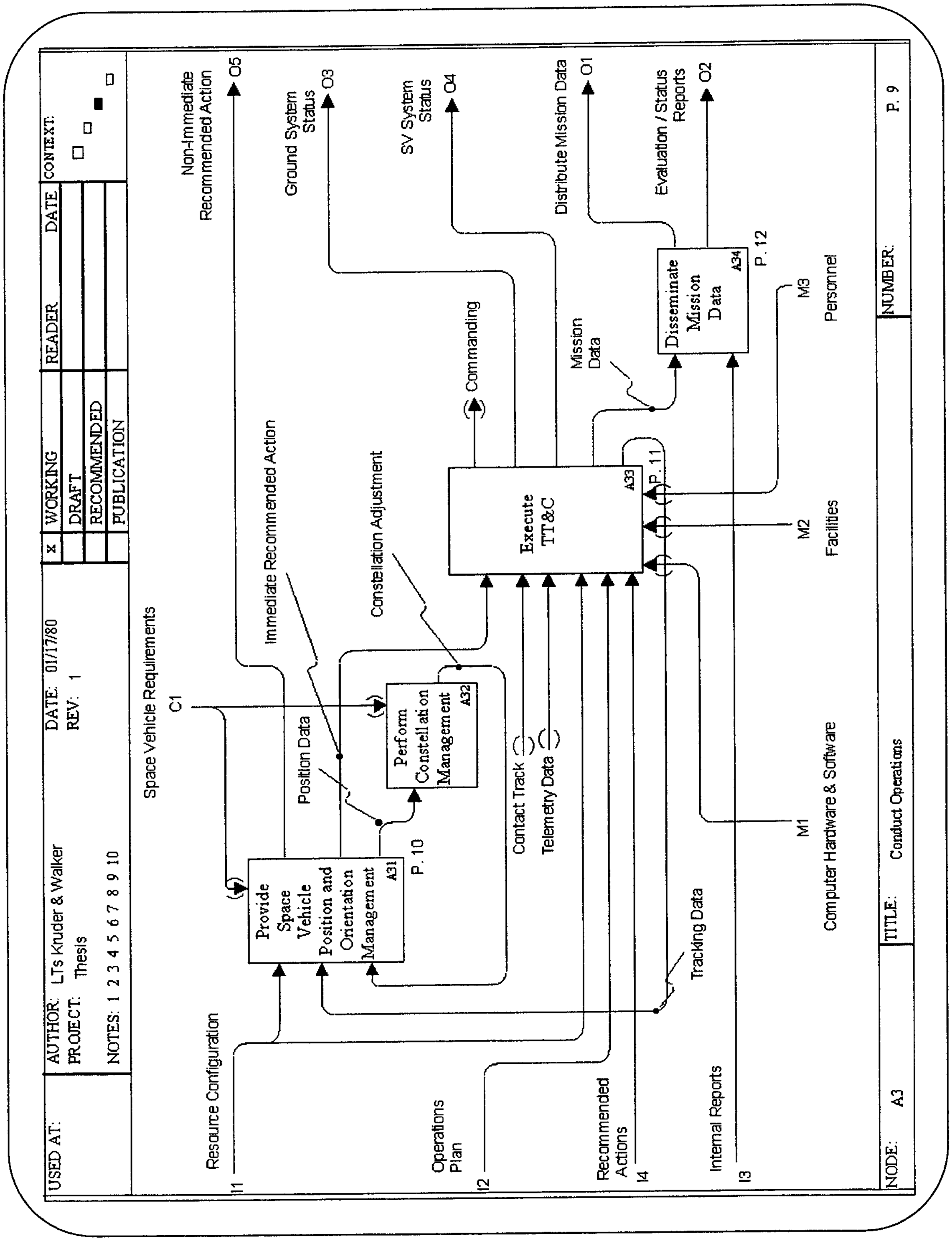


Figure 5, Conduct Operations

If the planning stage were known as the brains of the TT&C process, then the operations stage is its heart. It is here that the system answers the user's tasking and provides the desired results. It begins with the function, Execute TT&C, where signals sent from participating space vehicles are received. These signals are processed to reveal the information that they are carrying. The diagram labels the signals as either a contact track or telemetry data. Contact tracks provide information on tracking data which is utilized in determining a SV position and orientation. Whereas, telemetry data delivers information pertaining to the SV's health status and associated mission related data. At a later point, the health status, known as SV System Status, along with Ground System Status gathered from within the process of executing TT&C, becomes an input for analysis of the system's performance. Mission data is sent to the resources capable of disseminating it to the user in a form usable by that user.

Commanding a space vehicle is an ability critical to executing TT&C. A command to reorient a SV begins with a requirement for increased accuracy in determining the position of the SV. Position and orientation management allows for further precision of the tracking data. If the SV is associated with additional SV's, constellation management will provide any adjustment recommendations to ensure the integrity of that constellation. Time sensitive actions are sent directly to the function, Execute TT&C, to be processed into commands. These actions normally involve preventing or correcting an abnormality which could damage the SV. Non-immediate recommended actions are held until they can be incorporated into the operations plan. The plan contains a list of commands that will be transmitted to the SV at a specified time. This list and any immediate recommended actions are converted into appropriate command language and transmitted to the SV as scheduled.

Finally, the figure shows that internal reports are merged and prepared in the function, Disseminate Mission Data. It is through this route that users and other governing authorities receive requested reports on the status of the TT&C process and results of evaluation analysis.

d. Conduct System Analysis

Conduct System Analysis is the last of the four primary functions, and through its output, a continual feedback loop within the TT&C process is established. This feedback, in the form of internal reports and recommended actions to correct for abnormalities, allows the controlling agency to observe its performance, identify deficiencies and provide an avenue for improvement and growth. This function will present current as well as time trended system performance for evaluation by outside sources. Figure 6, Conduct System Analysis, illustrates how the five secondary functions, listed below, enable the process to acquire this detailed look at itself.

ASSOCIATED SECONDARY FUNCTIONS

- Determine Ground System Status
- Provide Ground Evaluation
- Determine SV System Status
- Provide Payload / Platform Evaluation
- Perform System Analysis

The analysis is conducted in three stages: a look at the ground segment, a separate look at the SV segment, and combined look to provide an overall evaluation of system performance. Analysis begins with current status reports being delivered by operations concerning both the ground and SV segments. Additional feedback from the user is utilized to evaluate the quality of the product produced by the space vehicle. The secondary functions dealing with determining ground and SV systems status receives their respected inputs and derives a health and status condition on each segment. Any abnormalities requiring immediate corrective response is accompanied with the activation of an alarm along with being highlighted on the health and status report.

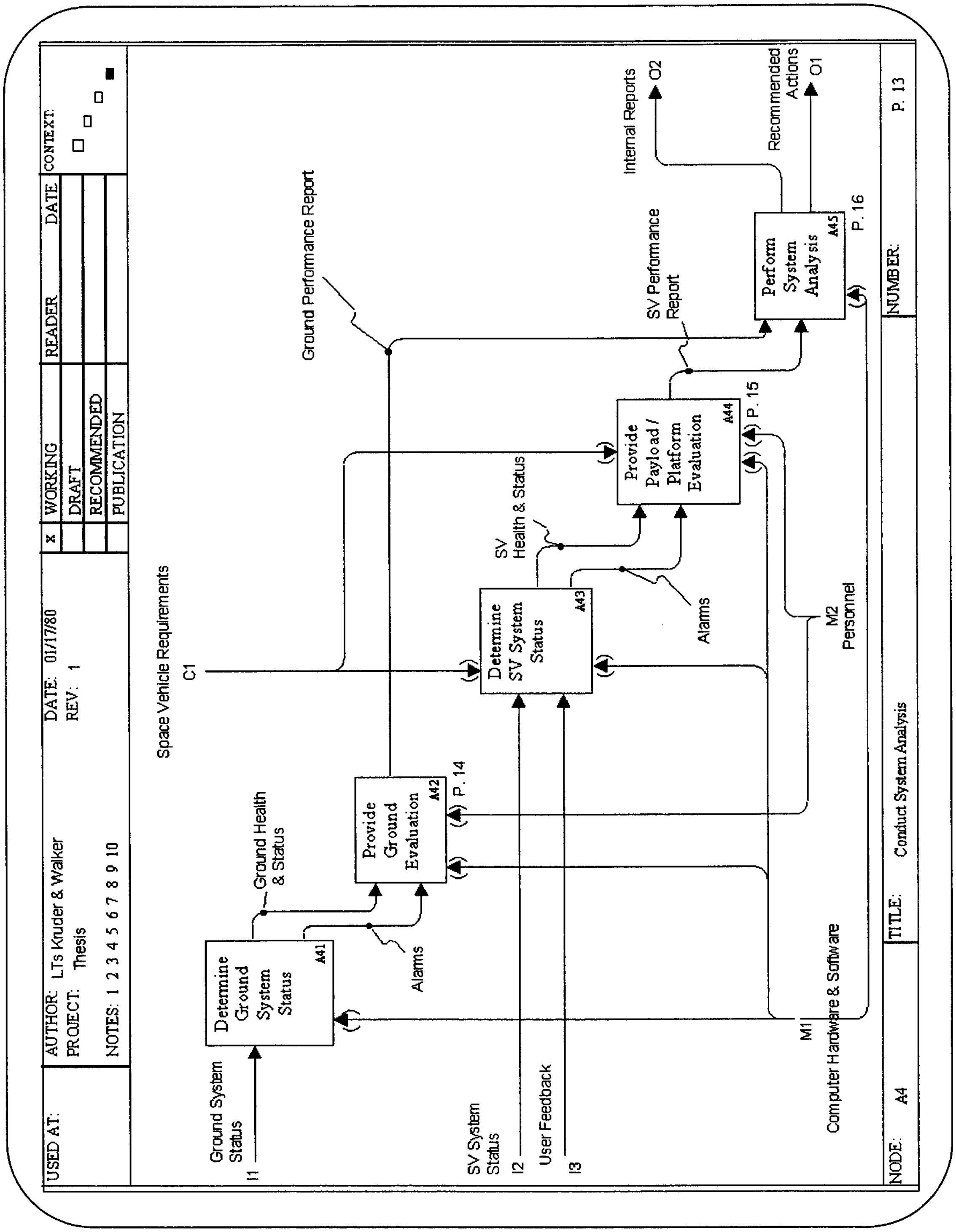


Figure 6, Conduct System Analysis

It is the functions which provide evaluations of the segments that actively seek out the cause of a problem and determine the degradation of a system. The findings are included in the performance reports and sent for final analysis.

Perform System Analysis is the final function which merges all the information inputed and formulates the recommended actions necessary to rectify any abnormality. It takes a complete look at the total process to ensure that actions taken on one particular system does not adversely affect other systems. The implementation of internal reports grants the other primary functions an opportunity to monitor their overall effectiveness based on time trended performance evaluations. It is these evaluations that create a loop within the TT&C process allowing feedback between all activities.

3. Secondary Functions and Associated Sub-Functions

The following section, along with the data dictionary found in Appendix B, provides further insight into the process of TT&C. The secondary functions, the immediate level which supports the primary functions, are listed in alphabetical order. Their definitions will include redefining essential inputs, outputs, controls and resources. Sub-functions are simply the next level in the process chain. They directly support a specific secondary function and will be listed immediately following the definition of that function. It is important to note that some secondary functions listed in this text are not associated with any sub-functions. The authors determined that certain functions required further break down in order to better aid the decision maker's understanding of the TT&C process. The remaining functions, as well as the sub-functions, were basically self evident and no further insight was required.

a. Allocate Resources

This is the ability to interpret SV support requirements into near term equipment utilization schedules for all elements of satellite control. The key inputs being an operations plan, internal reports, a logistic schedule, maintenance asset status, and personnel qualification status. Key outputs are resource configuration, support needs, and

available assets. A single controlling factor is identified as support requirements. Key resources are personnel and computer hardware & software.

ASSOCIATED SUB-FUNCTIONS

- Perform Scheduling of Operations per Operator
- Perform Network Scheduling
- Establish Pre-Designated Network Configurations

b. Conduct Logistics

This provides the capability of integrating non-flight essential supporting elements into an efficient logistic plan. Key inputs are the operations plan and internal reports such as a logistic request. The output being the logistic schedule. As always with logistics, the key resource is personnel required to take action.

c. Conduct Maintenance

This is the ability to perform routine, periodic, and unscheduled / time critical maintenance support on ground segment and related facilities. Associated inputs to this function are the operations plan and internal reports. The key output is the maintenance asset status report. The key resource to this secondary function is the personnel required to perform maintenance tasking.

ASSOCIATED SUB-FUNCTIONS

- Provide Maintenance Personnel
- Perform Routine / Periodic Maintenance
- Perform Logistic Support

d. Conduct Training

This is the ability to provide realistic training by utilizing classroom, on-the-job, and simulator environments. The key inputs associated with this function are the operations plan and internal reports. The output from this function will be a personnel qualification status report. The key resource is personnel, specifically instructors when dealing with training evolutions.

ASSOCIATED SUB-FUNCTIONS

- Provide Maintenance Personnel
- Perform Routine / Periodic Maintenance
- Perform Logistic Support

e. Determine Ground System Status

This is the method to detect and isolate problems in order to determine ground segment current status. The key input to this function is the Ground Segment Status. Outputs to this function are Alarms and Ground Segment Health and Status. Resources affecting this function are the Computer Hardware and Software.

f. Determine SV System Status

This is an ability to provide a method to detect and isolate problems in order to determine the space vehicle system's current status. The key inputs to this function are SV System Status and User Feedback. Outputs include Alarms and SV Health & Status. The single control affecting this function is SV Requirements. The two resources involved are Personnel and Computer Hardware & Software.

g. Disseminate Mission Data and Other Information

This allows for the capability of distributing processed and unprocessed data from the satellite control node to the C2 node (user). Additional information required by the user outside of mission related data would also be disseminated. Key inputs to this function are Mission Data (Processed and Unprocessed) and Internal Reports. The associated outputs are Distributed Mission Data (Processed and Unprocessed) and Evaluation / Status Reports.

ASSOCIATED SUB-FUNCTIONS

- Disseminate Processed Data
- Ability to Disseminate Unprocessed Mission Data
- Disseminate Evaluation / Status Reports

h. Execute TT&C

This function maintains the systems ability to receive telemetry data, gather and process azimuth and elevation data, as well as other pertinent navigation information. Also included in the function is the transmitting of commands necessary to control both payload and maintain health and status of the platform. Supporting functions include; receive data, collect and process pointing data, determine range and range rate, transmit payload commands, maintain health and status, provide antenna connectivity, concurrent events, and establish timing accuracy. Key inputs to this function are the Operation Plan, Immediate Recommended Actions, Recommended Action, Telemetry Data, Contact Data, and Resource Configuration. Outputs associated with this function are Commands, SV System Status, and Ground System Status. Resources belonging with this function are Computer Hardware & Software, Facilities, and Personnel.

ASSOCIATED SUB-FUNCTIONS

- Determine Range
- Collect and Process Pointing Data
- Calculate Azimuth and Elevation
- Establish Timing
- Receive Data & Command Verification
- Data and Control Commands

i. Perform Constellation Management

This is the ability to determine, predict, and adjust as necessary the SV orbital parameters in order to maintain constellation integrity. The key input associated with this function is Positioning Data. The resultant output being Constellation Adjustment. The associated control with this function is Space Vehicle Requirements.

j. Perform Operations Planning

This is the ability to perform all planning functions to include; mission planning, contact objectives, command generating, contingency, and time sensitive planning. Inputs involved are Deployment Plan, User Tasking, SV Requirements, Schedule Modification, Support Needs, Reconfiguration Plan, Recommended Actions, Internal Reports, and Available Assets. The key output to this function is the Operations Plan. Controls affecting this function are Space Policy, and the Mission Need Statements. A common resource associated with this function is Personnel.

ASSOCIATED SUB-FUNCTIONS

- Define Contact Objectives
- Perform Command Generation
- Perform mission Planning

k. Perform Payload Reconfiguration

This is the ability to provide a planning responsiveness to users that involves possible changes to the control of the platform or payload systems. The key inputs associated with this function are the User Tasking and SV Requirements. The associated output being the Reconfiguration Plan. Controls related to this function are SV Requirements and Mission Need Statements.

l. Perform System Analysis

This is the ability to evaluate overall system performance. It would include conducting long term trend analysis and capacity management evaluation. Key input parameters associated with this function are the SV Performance Report and the Ground Performance Report. Outputs from this function are Internal Reports and Recommended Actions. Controls affecting this function are the Antenna Network, Communication Capacity, Satellite Operations Center Requirements, and System Requirements. Resources belonging to this function are the Processor, Software, Capacity Models, and Trending.

ASSOCIATED SUB-FUNCTIONS

- Evaluation of Overall System Performance
- Conduct Long Term Tend Analysis

- Evaluate System Capacity

m. Provide Ground Evaluation

This provides for the ability to quickly assess, isolate, and correct ground system failures. Inputs belonging to this function are Alarms and Ground Segment Health and Status. Outputs associated are the Ground Performance Report. Resources falling under this function are Personnel and Computer Hardware & Software.

<u>ASSOCIATED SUB-FUNCTIONS</u>

- Conduct Isolation of Ground System Problem
- Notify Operator
- Recommend Corrective Action

n. Provide Payload / Platform Evaluation

The function maintains the ability to assess, verify, and conduct detailed performance analysis either during or after a SV contact. Key inputs to this function are the SV Health & Status and the Alarms. The output is the SV Performance Report. The key governing control to this function is SV Requirements. Resources affecting this function are the Personnel and Computer & Hardware & Software.

<u>ASSOCIATED SUB-FUNCTIONS</u>

- Conduct Isolation of System Problem
- Notify Operator
- Recommend Corrective or Safing Action

* Verify Mission Events

o. Provide Space Force Deployment

This function provides the planning for all aspects of Space Force Deployment. Activities involved include pre-launch preparations, launch support, early orbit checkout, and positioning of the SV.

p. Provide Space Vehicle Position and Orientation Management

This function provides the ability to determine, predict, and adjust orbital parameters of the SV within specified limits. The input is the Tracking Data. The outputs includes Position Data, Immediate Recommended Action, and Non-Recommended Action. The control on this function is SV Requirements.

ASSOCIATED SUB-FUNCTIONS

* Determine Space Vehicle Position and Orientation
* Predict Position and Orientation
* Adjust Orbital Parameters

q. Provide Schedule Additions

This function provides a responsive capability to the SV system user (either external or internal) to accomplish non - nominal or emergency support requirements (mission tasking). This entails formulating schedule options and resolving possible schedule conflicts. Key inputs to this function are User Tasking, Non-Immediate Recommended Action, and the Operations Plan. The output to this function is the Schedule Modification. Controls acting on this function are the Mission Need Statements and Space Policy. Personnel is the essential resource involved with this function.

ASSOCIATED SUB-FUNCTIONS

- Determine Schedule Options
- Resolve Schedule Conflictions
- Execution of Schedule Addition

D. SUMMARY

This chapter presented a generic look at the TT&C process by identifying essential functions and their interrelationship amongst each other. This was achieved by graphically presenting the four primary functions, associated secondary and sub-functions in a DOD accepted activity modeling technique. By understanding the process, the first step toward providing a comprehensive guideline to aid the decision maker is established. This guidance would focus the decision maker's areas of concern surrounding future proposed TT&C candidate architectures.

However, to ensure a completely informed decision, it will be necessary to examine present architectures and develop a method to objectively rank them. This will be the intentions of the following two chapters.

III. CURRENT TT&C METHODS AND TRENDS

A. INTRODUCTION

To properly make good judgmental choices for development of future TT&C architectures, it is essential that the decision maker have a well defined description of the current TT&C architectures. Currently, there exist a multitude of TT&C architectures that could be used to formulate this baseline. The options for discussion range from both national and international military and/or commercial oriented systems. This chapter will limit itself in an attempt to provide an in-depth descriptive look at three well known domestic options.

- Air Force Satellite Control Network (AFSCN)
- Mission Control Center (MCC), Johnson Space Center
- Naval Satellite Operations Center (NAVSOC)

These options were chosen on the basis of available material / resources and their non -proprietary nature. The options represent varying and distinct aspects to TT&C development. Their approaches to TT&C range from utilizing historically proven processes to the development and integration of advanced control / communication techniques.

B. AIR FORCE SATELLITE CONTROL NETWORK (AFSCN)

1. History

The AFSCN capability was established in 1959 in response to worldwide classified programs. Growing to match expanding user requirements, the AFSCN went from controlling just three satellites to presently 90 plus satellites projected for the end of 1997. As a result of its ability to validate technology, the Space Ground Link System (SGLS) established by the AFSCN has become the accepted DOD standard.

2. Command Structure

The AFSCN is under operational control of the Air Force Space Command (AFSPACECOM), headquartered at Peterson Air Force Base (AFB). The 50th Space Wing, headquartered at Falcon AFB, is responsible for the operation and management of the AFSCN. The 50th Space Wing Organizational Structure is shown in Figure 7.

3. Baseline Resources

a. Remote Sites and Antenna Capability

There are sixteen common-user TT&C remote tracking stations spread out over nine geographical locations shown in Table 1. Three Remote Tracking Stations, Mahe Indian Ocean (IOS), Falcon Air Force Base (FAFB) Colorado Springs (CTS), and Diego Garcia (DGS) are single sided, that is to say, they have only one TT&C antenna. Five of the remaining six sites, Manchester New Hampshire (NHS), Kaena Point, Oahu Hawaii (HTS), Vandenberg AFB (VTS), Oakhanger England (TCS), and Guam (GTS) are dual sided. Lastly, Thule Greenland (TTS) is triple-sided. Knowing that one side can provide services to one Space Vehicle (SV) at a time results in the previously stated sixteen common-user TT&C stations. An "S" band space-ground interface is utilized while primary and alternate AFSCN communications are maintained to the control centers. [Ref. 7]

The AFSCN Common-User Non TT&C facilities are Camp Parks Communication Annex (CPCA), located at Pleasanton CA; the Eastern Vehicle Checkout Facility (EVCF), at Cape Canaveral FL; and multiple mobile systems can perform TT&C functions with one SV at a time.

The dedicated control centers coordinate with the Operational Control Nodes (OCNs), Falcon Air Force Base and Onizuka AFB, for the scheduling and allocation of resources. An example would be Milstar Operations Center (MOC) at Falcon Air Force Base, Global Positioning System (GPS) Master Control Station (MCS) at Falcon Air Force Base, and Naval Space Operations Center dedicated to the FLTSATCOM program.

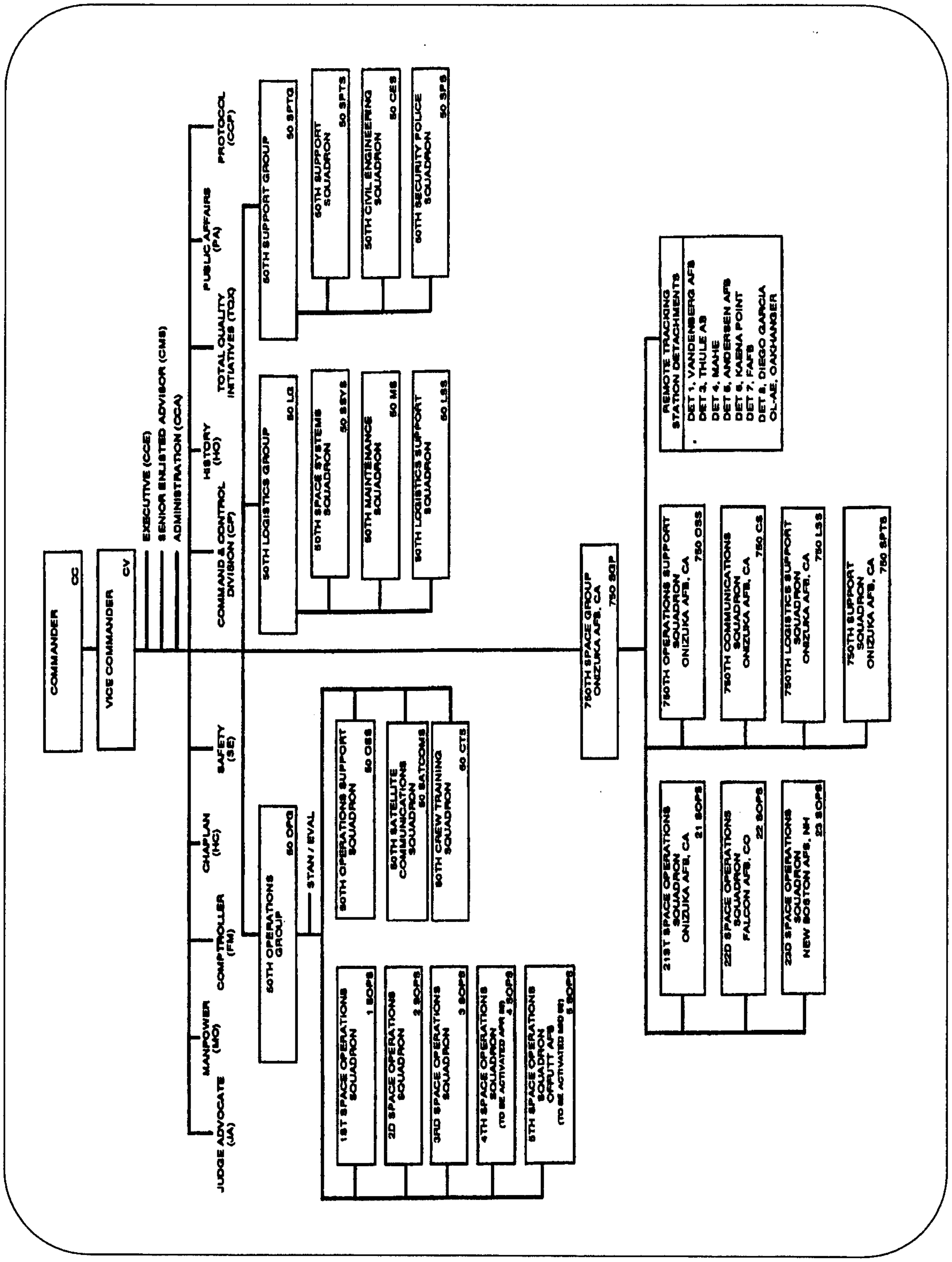


Figure 7, 50th Space Wing Organization, From Ref. 8

There are five non TT&C Monitor Stations (MS) all of which are dedicated to GPS. Of note, all five MSs have "L" band omni antennas used for tracking and monitoring the GPS satellites (i.e.: ephemera data collection).

Tracking Station	Number of Antennas
New Hampshire (NHS)	2 Space-Ground Link System (SGLS)
Vandenberg AFB (VTS)	2 SGLS
Kaena Point Oahu (HTS)	2 SGLS
Guam (GTS)	2 SGLS
Indian Ocean (IOS)	1 SGLS
Thule Greenland	3 SGLS
Oakhanger England (TCS)	2 SGLS
Diego Garcia (DGS)	1 SGLS
Falcon AFB (CTS)	1 SGLS

Table 1. AFSCN Common User TT&C Tracking Stations

b. Personnel

There are approximately 1200 personnel assigned to the AFSPACECOM. With the responsibility of over 90 plus satellites to control, this manpower level allows for a personnel to satellite payload ratio of 8:1.

c. Supporting Facilities

Supporting facilities for the AFSCN is provided within the command structure itself. These supporting facilities include some of the following:

- 50th Logistics Group - manages logistic support activities for the ground control systems.
- 50th Support Group - maintains and operates Falcon Air Force Base which would include physical security, and utilities & environmental support.

- 750th Space Group - located at Onizuka AFB CA, provides backup for TT&C support to AFSCN users.

4. Operational Methodology

The AFSCN is considered to be a centralized network revolving around the primary and secondary Mission Control Complex (MCC) located at either Falcon AFB or Onazuka AFB respectively. The operating methodology for the AFSCN is known as the Command and Control System (CCS). The CCS takes advantage of a centralized command & control structure which provides for user dedicated data processing. Inherent to the CCS system the Remote Tracking Stations (RTS) utilize the Remote Control and Status Equipment (RCSE) which allows the RTS to act as a geographic disperse relay site. This enables the RTS to directly relay the entire received telemetry stream back to a CCS- compatible MCC or act as a relay for SV commands from the CCS MCC to the SV. Because of centralized location of the main processors, all processing and analysis is conducted at the MCC site. As a result, real time access to the entire telemetry (TLM) stream is possible. The CCS architecture consists of the following major hardware items:

- Main Processors - Each MCC contains two main processors referred to as the Contact Support Processor (CSP) and the Planning and Evaluation Processor (PEP). [Ref. 9]

- Processor Peripherals - Storage peripherals include Direct Access Storage Devices (DASDs) and magnetic tape units. Display peripherals include interactive display terminals and hardcopy printers. [Ref. 9]

- Classified Interface Unit (CIU) - This unit receives and transfers data from the Command Contact Support Equipment Group (CSEG) and Isolation Review Unit (IRU) to the processor. Data includes pointing commands, RTS configuration directives, and SV commands. [Ref. 9]

- Unclassified Interface Unit (UIU) - This unit receives and transfers data to and from the CIU via the IRU and or Command CSEG. Data includes tracking and RTS status, RCSE ground directives, and encrypted SV commands. [Ref. 9]
- Isolation Review Unit - Receives data being transferred from the CIU to the UIU and returns data that does not pass security reviews back to the CIU. [Ref. 9]
- Telemetry Interface Unit (TIU) - The TIU receives data from the telemetry CSEG and transfers the data to the CSP. [Ref. 9]
- Telemetry CSEG - The telemetry CSEG preprocesses, synchronizes, and decrypts telemetry data. [Ref. 9]
- Command CSEG - The CSEG encrypts command data originating in the CSP and decrypts command echo data. [Ref. 9]

A descriptive diagram can be found below in Figure 8, AFSCN Satellite Control Architecture.

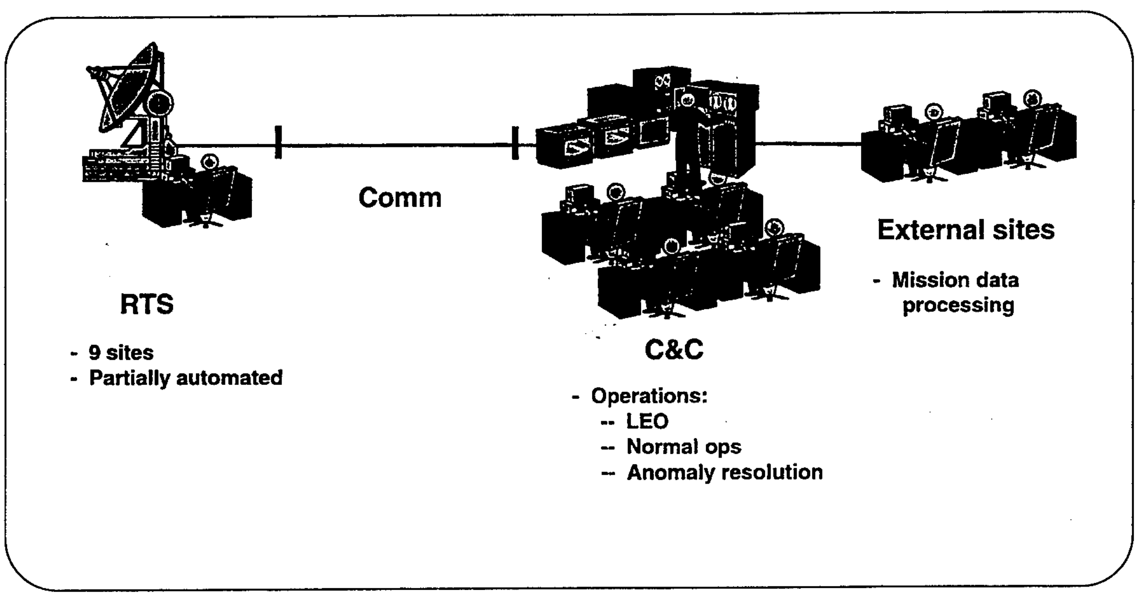


Figure 8, AFSCN Satellite Control Architecture, From Ref. 10

5. Strengths and Capabilities

The AFSCN architecture strengths lie in the following areas:

- Establishment of a worldwide antenna network providing global coverage
- Support launch and space force deployment
- Current infrastructure allows for the management of a large volume of space vehicles
- On - orbit commanding / support of SVs

C. NAVAL SATELLITE OPERATIONS CENTER (NAVSOC)

1. History

With the development of the TRANSIT satellite system to meet Fleet Navigation Requirements, the Naval Satellite Control Network (NSCN) became operational in 1962. The NSCN currently provides support for less then thirty satellites. With only three remote sites and one SGLS antenna per site, the NSCN is acclaimed for its use of open and distributed architecture strategies and Commercial Off the Shelf (COTS) implementation.

2. Command Structure

The Naval Satellite Operations Center (NAVSOC), located at Point Mugu CA, provides the command and control of satellite systems assigned by the Naval Space Command (NAVSPACECOM), headquartered at Dahlgren, VA. The NAVSOC operates and maintains the NSCN which comprises all of the satellite TT&C ground-based hardware and software. A descriptive view of the organization is provided in Figure 9, NAVSOC Organization.

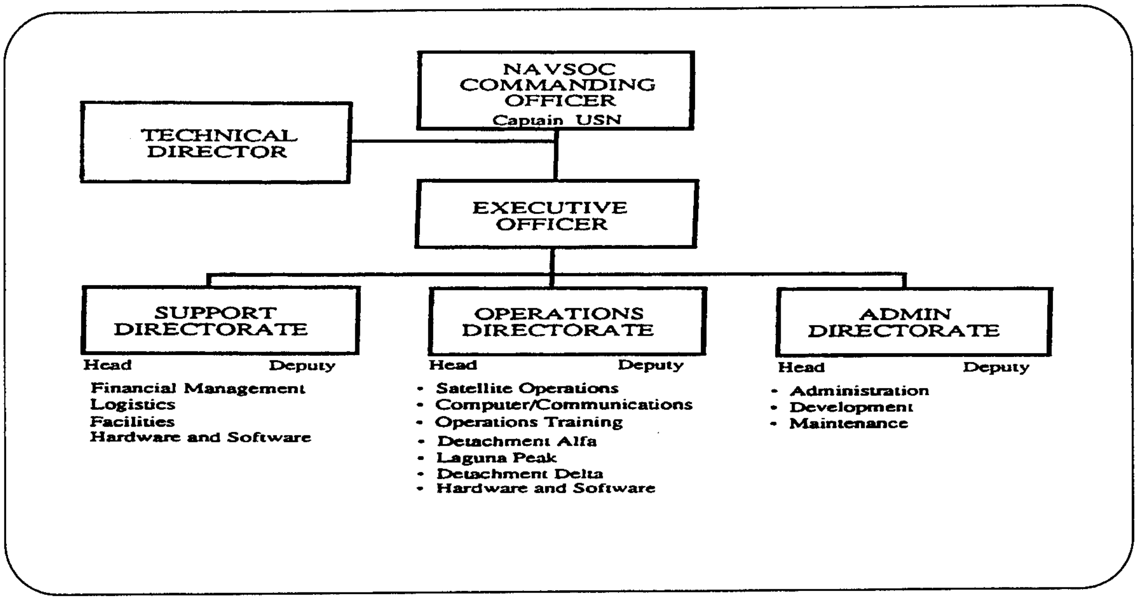


Figure 9, NAVSOC Organization, From Ref. 11

3. Baseline Resources

a. Remote Sites and Antenna Capability

The NSCN remote sites are located in Table 2, NSCN Remote Sites and Capabilities. The basic configuration of each site is similar except that the Laguna Peak and Detachment Alpha have the satellite-ground link system (SGLS) capability for satellite-to-ground communications. Currently there are no intentions to command from the Guam site due to the AFSCN Automated Remote Tracking Stations (ARTS) integration plan which calls for the sharing of AFSCN antenna sites assets on an as-required basis. [Ref. 11]

Tracking Station	Number of Antennas
Prospect Harbor, Maine (DET ALPHA)	2 EHF, 1 SGLS, 1 VHF
Rosemount, Minnesota (DET BRAVO)	3 VHF (Transit Only)
FAFB, Colorado Springs, CO (DET DELTA)	1 SGLS (Shared)
Laguna Peak, CA	1 SGLS & VHF, 1 VHF
Guam (DET C)	1 SGLS, 1 EHF (UHF Follow-On)

Table 2. NSCN Remote Sites and Capabilities

The architecture at each remote site comprises the following five subsystems: SGLS antenna subsystem, Doppler tracking subsystem, TT&C subsystem, Integrated Satellite Control System (ISCS) component subsystem, and Communication subsystem. The Communication Subsystem provides connectivity to non-NSCN systems, the other remote sites, and NAVSOC HQ.

b. Personnel

The NAVSPACECOM operates with a manpower level of approximately 180 personnel and 17 operational satellites which results in a personnel to satellite ratio of approximatley 10:1.

4. Operational Methodology

The NAVSOC uses a distributed architecture globally (on a WAN basis) where all the components of hardware and software are standardized. The basic configuration of each site is similar, expect that the Laguna Peak and Detachment ALPHA remote sites have satellite-ground link system (SGLS) capability for satellite-to-ground communications. The Integrated Satellite Control System (ISCS) is the methodology for performing NSCN satellite operations. The ISCS takes advantage of VAX hardware & software systems and uses the Naval Research Laboratory's (NRL) Common Environment for Testing (COMET) / Command and Telemetry System (CATS) software. The NAVSOC is currently progressing steadily toward an open architecture by utilizing

workstations and PCs. Eventually, the VAX systems will be replaced by a combination of PC type file servers and workstations.

Through the implementation of ISCS each RTS can perform the following functions:

- Evaluate telemetry and pass change only telemetry data to the communications subsystem for transmission to NAVSOC HQ
- Evaluate telemetry limits and generate anomaly alerts.
- Store telemetry data in designated formats.
- Control antenna pointing based on satellite orbital elements received from the external system
- Evaluates the ISCS software processes and generates anomaly alerts
- Develops the schedules of all NSCN satellite contacts
- Configures and controls ground station hardware components
- Construct and store commands and command sequences and will initiate the command uplink to the satellite

It should be noted that at the time of this writing, NAVSOC HQ does not have an antenna on site to provide SGLS communications due to the close proximity of the Laguna Peak site. However, the distributed architecture which NSCN employs allows the NAVSOC HQ the capability to control and collect data from or for any site within the NSCN. A descriptive diagram is shown in Figure 10, NAVSOC Satellite Control Architecture. The NSCN is comprised of the following major components:

- Remote Site ISCS - Each site contains a Micro VAX computer which is connected to a Thinwire Ethernet Local Area Network (LAN). The LAN connects the Micro VAX to the telemetry and communications subsystems in the normal operational mode by using RS-232 interfaces. [Ref. 11]

- HQ ISCS - This component contains redundant Micro VAX computers that perform the previously mentioned functions. [Ref. 11]

- ISCS Software - Menu driven command and control system operating on a Micro VAX computer. Basic software consist of VMS operating system, COMET / CATS, NRL developed software, and NAVSOC specific software. [Ref. 11]

- Communications - The communication component links the remote sites to NAVSOC HQ and other NSCN sites through a DECrouter. A dial up connection between remote sites and NAVSOC HQ provides a backup capability in degraded operational modes. [Ref. 11]

- Intersite Communications - Currently, all sites are linked via multiplexers on 56 Kb/sec leased lines and a point-to-point packet network. The point-point packet network is implemented by the use of a commercial network architecture known as DECnet. The DECnet uses one channel out of 8 possible. The remaining channels are used for passing real-time baseband data, voice & fax communications, antenna control, receiver, and bit synchronizer if the site computer is not available. The leased lines provide the data links among the three sites, allowing each site to communicate directly with NAVSOC HQ. At each site, the leased lines terminate in a modem, a KG-84, and a DECrouter hardware string. [Ref. 11]

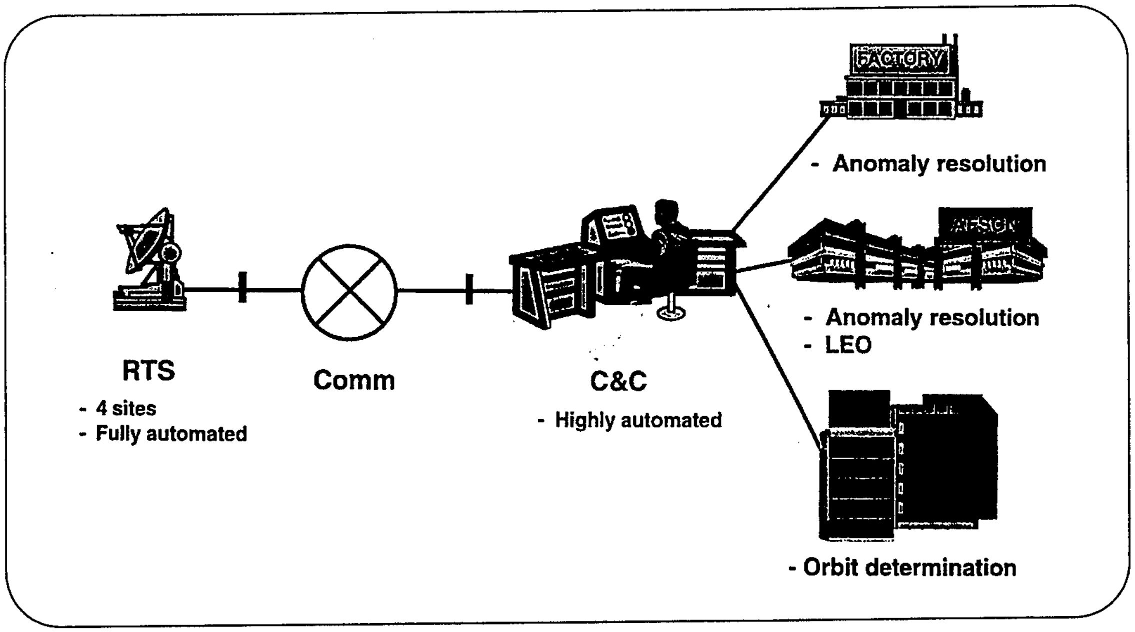


Figure 10, NAVSOC Satellite Control Architecture, From Ref. 10

5. Strengths and Capability

The NSCN architecture exhibits the following strengths and capabilities:

- COTS and International Standardization implementation throughout architecture
- Distributed aspect of the system permits remote sites and HQ to act as backup allowing for multiple redundant systems in case of system degradation.
- High level of automation allows for timely processing of Anomaly Analysis, Alarms, Corrective Action and Scheduling. This also enables a reduction in required personnel to accomplish these tasks.
- Considerable potential for growth through the implementation of the Plug - In - Use concept allows access to other non NSCN assets. In addition, limited commanding capability for UFO Follow on and FLTSAT satellites has been achieved through this method.

D. MISSION CONTROL CENTER (MCC), JOHNSON SPACE CENTER

1. History

Since 1964, the Mission Control Center (MCC), located at Johnson Space Center Houston, has undergone a drastic metamorphosis which enabled it to meet current space vehicle mission requirements while meeting the present day economic demands. The MCC takes advantage of both COTS and the present day open architecture technology. Unlike the limited role of the NSCN, the MCC is required to handle a vast array of mission tasking; most importantly, that being the manned space flights and deep space programs.

2. Command Structure

The MCC is organized under the Director of Space Shuttle Operations Office, who's responsibilities include all aspects of NASA's highly visible operation, the Shuttle Transportation System (STS) Program. The Johnson Space Center (JSC), in which the MCC is an integrated part, and Kennedy Space Center (KSC) provide the required monitoring capabilities to ensure safe STS operations. The Director of Space Shuttle Operations delegates MCC operations and tasking to the manager of the Space Shuttle System and Operations Office. It is this office which is responsible for day to day manning of the flight director position. These individual flight directors personally oversee the operators of the MCC facility. Figure 11, MCC Command Structure, depicts a broad overview of the Space Shuttle Program Office.

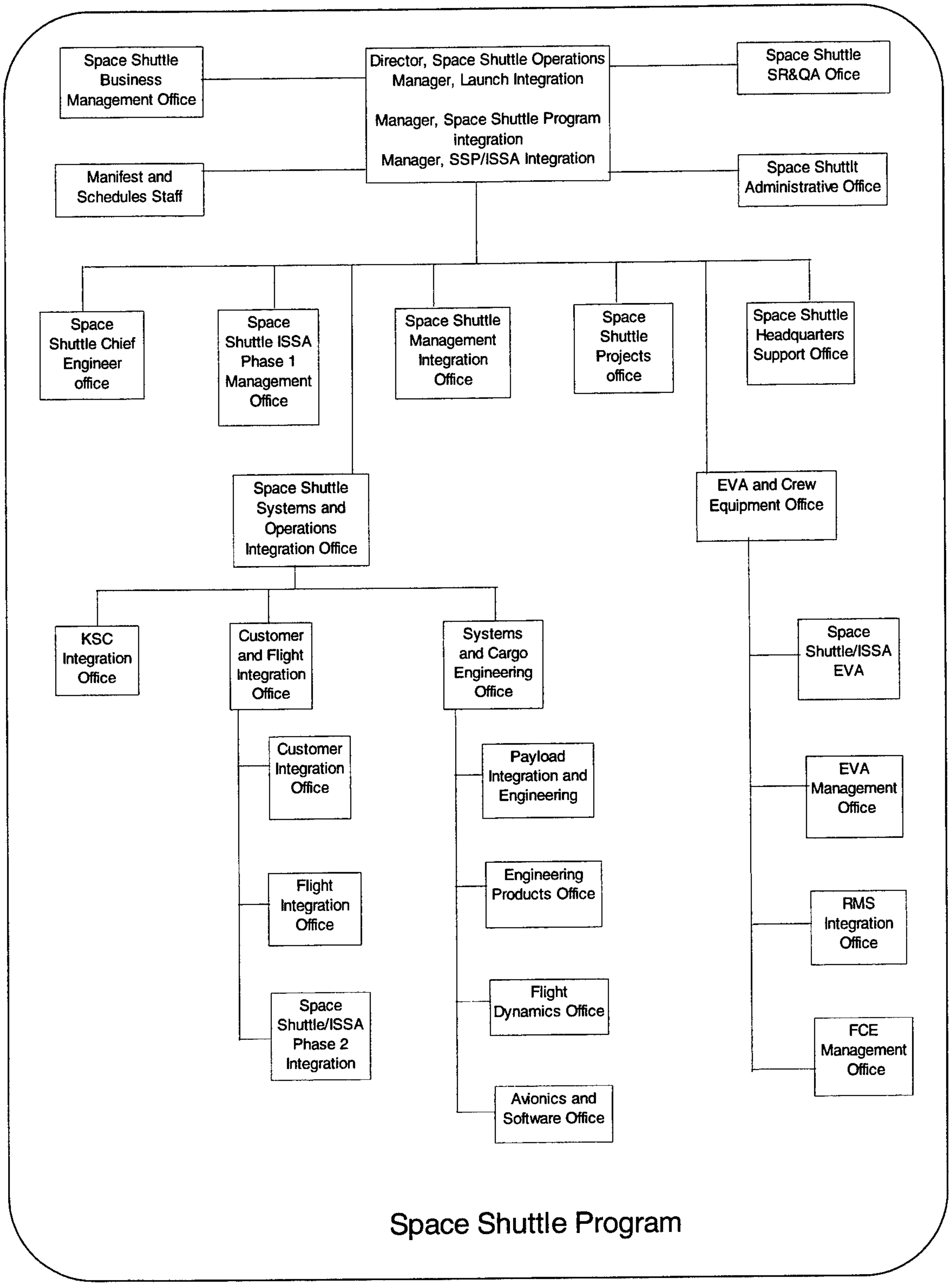


Figure 11, MCC Command Structure, From Ref. 12

3. Baseline Resources

a. Remote Sites and Antennas

NASA receives data on S-Band, C-Band and KU-Band frequencies. Space Shuttle data and voice is downlinked via TDRSS Satellites or via ground stations. All TDRSS downlink is received at the NASA Johnson Space Center (JSC) through the White Sands Test Facility in New Mexico. All ground site downlink is received at NASA Johnson Space Center through either Sunnyvale CA, Goddard Space Flight Center (GSFC) or Kennedy Space Center (KSC). Appendix C identifies all the available ground sites utilized by NASA to receive Space Shuttle downlink.

b. Personnel

By reducing maintenance costs and increasing automation, the MCC has been able to reduce its staffing by 180 personnel while simultaneously growing overall operations capabilities to support Shuttle and future Space Station operation requirements. Currently, the MCC conducts operations with approximately 240 flight controllers on a three shift basis (80 per shift) and 75 ground controllers (25 per shift). The number of payload operators varies widely and is payload specific. Due to the nature and risk involved with manned space flight the MCC operates with a personnel to space vehicle ratio of approximately 315:1.

4. Operational Methodology and Capabilities

Operational systems include standard UNIX computer workstations using the DEC Alpha 500 platform for console operations, the IBM RS 6000 for front end processing with the Loral LI 550 telemetry processor for data operations. All workstations are interconnected on a Local Area Network (LAN) utilizing 125,000 ft of Fiber Optic Cable. The MCC boast having the worlds largest Fiber Optic Distributed Interface Network currently in use.

MCC Houston baselines the use of Commercial Off the Shelf (COTS) software and hardware where practical and estimates a reduction in lines of code from 4.6 million to 3 million by fiscal year 1999. Software standards for Terminal Communications Protocol / Internet Protocol (TCP/IP) communications protocol using the Fiber Data Distributed Interface (FDDI) network standard form the standards for the MCC communications backbone. Figure 12, MCC Satellite Control Architecture, provides a graphical representation of this architecture.

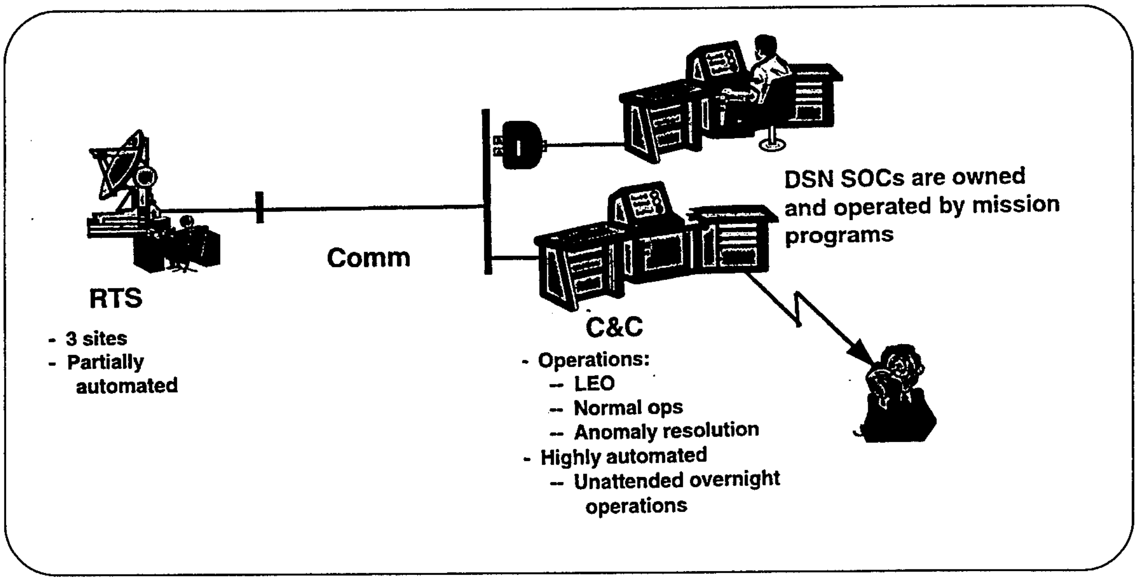


Figure 12, MCC Satellite Control Architecture, From Ref. 10

5. Strengths

The strengths of the MCC methodology stems from its fundamental underlying principle which is to build a world class Mission Control Center able to support multiple spaceflight programs while reducing long term operations and maintenance cost. In doing this the MCC has been able to construct a Mission Control Center that has the capability of providing rapid reconfiguration for the support of a variety of mission objectives while maximizing the use of COTS hardware and software.

E. TRENDS IN TT&C

As stated above, the strengths of the current TT&C systems, supported by the documentation presented in Chapter I, emphasizes a capability of doing business differently. This necessity for change is being driven by budgetary constraints, reduction in available resources, and the ever changing technological environment. This forces organizations to incorporate the cutting edge of technology at the same time ensuring lower life cycle cost, simplified process, reduction in manpower, while maintaining the ability to meet future program requirements. In the authors opinion, utilizing this approach would allow a transition from the traditional 60's mainframe architecture to the less manpower intensive, highly automated, and more standardized approach that is becoming the signature of the 90's.

The following trends were identified as being crucial in bringing current systems into the 90's:

- Automation - The ability to perform a specific task without human interaction. Advantages of automation include freeing operator time which may result in a reduction in manpower and act as a safeguard minimizing human error in a specific task. Such tasks may include: SV pass scheduling, health monitoring, sending commands, and trend analysis.

- Commercial Off The Shelf (COTS) - An item of hardware or software that has been produced by a contractor and is available for general purchase. Benefits from COTS implementation allows for timely integration at a reduced cost while using current technology. Examples would include acquiring the use of off the shelf operating environments such as X-Windows and commercially available personal computers (PC) / workstations.

- Distributed System - A decentralized system that is dispersed over an interconnected network. Benefits can include reduced cost as a result of not relying on centralized systems. This allows for a system which is multitasked,

the capability to achieve a robustness and redundancy level which is cost effective. An example would be allowing a single workstation at a specific site the ability to control not only on-site resources but that of shared resources located at remote sites.

- Open Architecture - A system that implements open specifications for interfaces, services, and supporting formats to enable properly engineered applications software: (a) to be ported with minimal changes across a wide range of systems, (b) to incorporate with other applications on local and remote systems, and (c) to interact with users in a style that facilitates user portability. The inherent benefit is that it allows future developing systems to use existing resources that can be shared or ported across an interconnected network. [Ref. 4]

- Plug-In-Use - Until the establishment of a truly open architecture, Plug-In-Use will provide individuals access to another's resources. The advantage is a lower total cost because the development of a simple black box which allows a system to communicate to an initially non-compatible resource is less expensive then building a dedicated resource which would be compatible to the original system. An example of implementing this concept would be the option currently undertaken by NAVSOC that allows direct commanding of satellites through the use of the AFSCN established antenna network.

- Operator System Interface - The interaction between the operating system and operator which allows the operator the ability to disseminate the graphically represented data. The tendency now is towards simplified icon oriented graphic representations of system status's which allows for ease of use while cutting down on required console training requirements.

- Open System Interconnection (OSI) - The OSI model is the formulation of protocols used for data communications. It sets down a set of rules governing

communications between systems and defines the functional operation of the communications between user and network elements. A current example would be the Space Communications Protocol Standards (SCPS) which incorporates the OSI model and dictates the packaging sequence for communication between ground station and SV's. The use of SCPS would prevent the future development of satellites with proprietary communication methodology which would require additional expensive handling from current TT&C facilities. The resultant is reduced space operations costs and improved interoperability.

The Decision maker needs to identify the above mentioned trends in a proposed architecture. If the above mentoned trends are implemented, two criteria must be determined; (1) ensure that the benefit of that trend is occurring and (2) recognize to what degree this trend is beneficial.

In the following chapter, an assisting tool to the decision maker will be provided that will determine the degree of benefit of an overall proposed architecture. However, if the decision maker cannot identify the use of the trends, he / she must question the proposer of the architecture to identify what achieves the benefits of lower life cycle cost, manpower reduction, simplicity of process, and potential for growth. Once this has been answered and using the tool provided in Chapter IV, the decision maker will be able to determine if this is an acceptable risk.

IV. COMPARISON METHODOLOGY

A. INTRODUCTION

Recall that in Chapter I, it was stated that the primary goal was to provide a methodology capable of comparing current and future TT&C candidate architectures. By rating candidates, the attempt is to reduce O&M cost, improve efficiency while maintaining mission effectiveness, and solidify space vehicle control requirements. To accomplish this, the decision maker is specifically tasked to develop and apply a structured methodology to allow scoring and ranking of candidate architectures in terms of their operational merit and cost. It is important to note that operational merit is an objective rating of measures in both effectiveness and performance of individual architectures. Whereas, cost will primarily deal with the overall life cycle cost. The analytic hierarchy process (AHP) presents itself as an ideal method in achieving this primary goal. In addition to presenting the AHP process, the authors will provide an illustrated example that will execute the step by step procedures to aid in comprehension.

1. The Analytic Hierarchy Process

The analytic hierarchy process (AHP), developed by Thomas L. Saaty, is designed to solve complex problems involving multiple criteria. The process can be divided into the following steps:

- Develop a hierarchy or graphical representation of the problem in terms of the overall goal, criteria, and the decision alternatives.
- Develop a scaling methodology to enable an unweighted ranking of decision alternatives based on the criteria.
- Establish significant relationships between multiple criteria's through a pairwise comparison methodology.
- Calculate a final weighted ranking of the decision alternatives.

- Develop a cost hierarchy of each decision alternative.

The above steps require the creation of working groups capable of identifying essential criteria which is quantifiable and pertinent to the overall goal. Once a list of criteria has been established, the working group must conduct two tasks. First, through an established scaling method, the group ranks each of the decision alternatives on each of the criteria. Finally, the relative importance between each individual criteria must be established. AHP recommends a pairwise comparison method to achieve this. Once the two tasks are completed, a mathematical procedure, known as synthesization, is used to develop a weighted ranking of decision alternatives. The last stage is to provide a cost hierarchy of each decision alternative. This cost hierarchy, along with the weighted ranking, will provide the decision maker with the decisive tools necessary to make an informed decision. [Ref. 13]

B. DEVELOPMENT OF AN EQUAL WEIGHTED RANKING

The initial step in AHP, as outlined above, is to provide a list of criteria's to evaluate candidate architectures. From Chapters II and III, it was determined that the method to achieve this would be through identifying the primary performance / system drivers. These drivers would be essential in accomplishing all functions regarding planning, operations, system networking, and analysis. After thorough evaluation, eleven predominant drivers were revealed as likely candidates for a formation of a criteria list. It is important to note that through further research and analysis, additional drivers may be incorporated into this list. The following section will identify each individual system / performance driver and provide an associated scaling method. To rank a driver's ability to accomplish a specific function, a scale with values ranging from 0 to 3 was developed. These ranging values were associated with certain attributes capable of being included in the design of a candidate architecture. In some cases, a driver will not be presented with a complete 0 to 3 range for scaling values because of limiting attributes. An example can

be found below when discussing the driver *standardization,* the number zero was not used.

1. TT&C System / Performance Drivers and Associated Scaling

a. Capacity

Capacity allows for the following: advanced capacity management planning ability; data rate easily variable to 25 Mbps based on user needs; and distributed open computing environments for easily expandable data processing capability. The rating scale for capacity is:

- 1 implies the architecture exhibits only minimal growth capacity: meets one attribute or less
- 2 implies the architecture exhibits only moderate growth capacity: meets two attributes
- 3 implies the architecture exhibits a high growth capacity: meets all three attributes.

b. Flexibility

Flexibility is a driver that takes into account automated mission planning and or scheduling; easily expandable and reconfigurable communications capability; secure system configurations to allow for operations across all classification levels; and lastly distributed open computing environments to allow rapid operational changes. The rating scale for flexibility is:

- 1 implies only minimally flexible: the architecture exhibits less than two of the above attributes
- 2 implies moderately flexible: the architecture exhibits two or three of the above attributes

- 3 implies highly flexible: the architecture exhibits three or more of the above attributes.

c. *Information Timeliness*

This attribute is a measure of the architecture to satisfy all requirements levied on the space vehicles control system by the operational tasking, in a timely manner. The rating scale for Information Timeliness is:

- 1 implies the architecture in question cannot satisfy all the requirements as based in the OPLAN and user requirements documentation
- 2 implies the architecture in question can satisfy all requirements .

d. *Maturity*

Maturity is a measure of the state of development of the proposed architecture. If the architecture is or has been operating in a fully operational mode, then the candidate may be considered mature. If the candidate is based on technology under development and does not currently exist, then the architecture is in a conceptual state and cannot be considered mature. It is understandable that there will be some overlap between maturity and technical risk. The rating scale for maturity is:

- 1 implies Conceptual : greater than 9 years to produce
- 2 implies Research: 5 to 9 years to produce
- 3 implies Development: 0 to 5 years to produce

e. *Relative Cost*

Relative cost is the cost to research the technical issues, develop, test and field the proposed TT&C architecture. The relative cost is not given in terms of cost versus effectiveness of the system, but use of the other eleven drivers will result in a higher ranking for a more cost effective system. The rating scale for relative cost is:

- 0 implies Very High
- 1 implies High
- 2 implies Medium
- 3 implies Low.

f. Reliability

That architecture which exhibits the following: expandable high data rate distributed workstations and broadened communications network; automated error detection and correction; and no mission impacting single point of failure. The rating scale for Reliability is:

- 1 implies the architecture exhibits only minimal reliability or availability: meets one attribute or less
- 2 implies the architecture exhibits only moderate reliability or availability: meets two of the attributes
- 3 implies the architecture exhibits a high reliability or availability: meets all three attributes.

g. Reporting & Tasking

Reporting and tasking takes into account the following: distributed open computing environment with interface to existing external standard command and control systems for near real-time reporting and current status updates based on operational requirements; and distributed open computing environment with interface to external standard command and control system for near real time tasking response based on operational requirements. The rating scale for Report and Tasking is:

- 1 implies the candidate architecture does not meet any of the attributes associated with reporting and tasking

- 2 implies the candidate architecture meets only one of the attributes associated with reporting and tasking
- 3 implies the candidate architecture meets all of the attributes associated with reporting and tasking.

h. Standardization

The standardization of a TT&C architecture looks at the standard interfaces for all applications within the system and to all external users. The attribute also takes into account minimum need for dedicated resources or payload specific configurations. Finally, the driver takes into account the standard communications protocols and interfaces for voice, data, and video.

The rating scale for standardization is:

- 1 implies minimal use of standardization: meets one of the attributes
- 2 implies moderate use of standardization practices: meets two of the attributes
- 3 implies a high use of standardization practices: meets all three attributes.

i. Survivability

This attribute is a measure of an architecture's capability of operating in a mobile/transportable environment in support of warfighting missions. The driver also considers malicious attacks on the system by either conventional or informational methods. The rating for survivability is:

- 1 implies architecture cannot operate in a mobile / transportable environment
- 2 implies the architecture can operate effectively in a mobile / transportable environment.

j. Technical Risk

The technical risk is determined by evaluating the current state of technology versus the technology necessary to employ a proposed candidate architecture. The risk involved is the risk of developing the technology in the time frame necessary to support employment of a new system. The rating scale for technical risk is:

- 1 implies High: major technical problems to resolve
- 2 implies Medium: moderate technical problems to resolve
- 3 implies Low: only minor technical problems to resolve.

k. Training

This attribute allows for the direct connectivity between the space vehicle operations center and the space vehicle control simulation systems (training facilities). The rating for this attribute is:

- 1 implies no standardized interfaces for interactive training or direct connectivity between operations centers and training centers
- 2 implies implementation of standardized interfaces for interactive training and support for direct connectivity between operations centers and training centers.

2. Development of an Equal Weighted Ranking Matrix

The authors evaluated the AFSCN, MCC, and the NAVSOC architectures using the eleven system / performance drivers and the rating scale presented in the previous section. The results are presented in Table 3, Equal Weighted Ranking of TT&C Architectures. This ranking assumes that all the performance drivers are of equal weight. As a result of completing Table 3, NAVSOC is revealed as the most favorable candidate architecture based on its level of performance.

TT&C Drivers	AFSCN	MCC	NAVSOC
Capacity	1	1	1
Flexibility	1	2	3
Information Timeliness	2	2	2
Maturity	3	3	3
Relative Cost	3	2	2
Reliability	1	3	2
Reporting & Tasking	1	2	2
Standardization	1	2	2
Survivability	1	1	2
Technical Risk	3	2	2
Training	1	2	2
Unweighted Score	18	22	23
Unweighted Ranking	3	2	1

Table 3, Equal Weighted Ranking of TT&C Architectures

C. RELATIVE SIGNIFICANCE OF SYSTEM / PERFORMANCE DRIVERS

Since the development of Table 3 assumed that all weights were of equal importance, the next step would be to determine how to assign weighting factors to the individual performance / system drivers. Recall that in Section A of this chapter, AHP was indicated as the method to achieve this task. While a more complete description of AHP can be found in Reference 13, Section A further states the description for this process.

1. Pairwise Comparison of Drivers

The task of weighting the performance / system drivers begins with identifying a working group, consisting of a variety of system experts, and an established scaling criteria. The final result of the working group is a scaled driver relationship obtained through pairwise comparison. This method of comparison forces a subjective opinion on how well one attribute stands against another. A list of attributes can then be prioritized from highest to lowest in relative importance.

In an attempt to illustrate this procedure, a working group consisting of Naval Post Graduate School students from the Space Systems Operations curriculum was utilized. This working group was provided a survey questionnaire which enabled them to conduct a pairwise comparison of the eleven identified critical drivers. A complete copy of the survey questionnaire is provided in Appendix D. Table 4, The Rating Scale, was provided to the working group as the agreed upon method of scaling.

Scale Value	Description
9	Extremely More Important
8	Strongly More Important
7	Moderately More Important
6	Slightly More Important
5	Equally Important
4	Slightly Less Important
3	Moderately Less Important
2	Strongly Less Important
1	Extremely Less Important

Table 4, The Rating Scale

To achieve a graphical representation, a pairwise comparison matrix based on the number of critical attributes is created. In this illustrated example, an eleven by eleven matrix was developed which matches the number of critical drivers identified. The axis of this matrix list these eleven drivers and provides a space to record the value of each pairwise comparison derived from the data collected from the survey questionnaire. The results of the working group survey questionnaire is presented in Table 5, Relative Significance Of TT&C Drivers.

	Capacity	Flexibility	Information Timeliness	Maturity	Relative Cost	Reliability	Reporting & Tasking	Standardization	Survivability	Technical Risk	Training
Capacity	5	5	4	6	6	4	5	5	4	6	5
Flexibility	6	5	4	6	6	4	5	5	5	5	5
Information Timeliness	6	6	5	6	7	4	5	6	5	6	6
Maturity	4	4	4	5	5	4	4	5	3	5	4
Relative Cost	4	4	3	5	5	3	4	5	3	5	4
Reliability	6	6	6	6	7	5	7	7	5	6	6
Reporting & Tasking	5	5	5	6	6	3	5	5	5	5	5
Standardization	5	5	4	5	5	3	5	5	4	5	5
Survivability	6	5	5	7	7	5	5	6	5	6	6
Technical Risk	4	5	4	5	5	4	4	5	5	5	5
Training	5	5	4	6	6	4	5	5	4	5	5

Table 5, Relative Significance of TT&C Drivers

2. Development of Normalized Driver Relationship Table

To further aid in the ease of presentation it is beneficial to normalize Table 4-3. This is accomplished by summing the individual columns and then dividing each entry in the column by the column sum. Table 6, The Normalized Relative Significance of TT&C Drivers, is the product of this procedure. Prior to calculating the weighted ranking of candidate architectures, the means from each row of the normalized table must be computed. The mean of each critical driver is shown in its own separate line at the bottom of Table 6.

After completing the table, it revealed that the three most important drivers were Reliability, Survivability, and Information Timeliness. Additionally, it showed that the least favorable driver was Relative Cost which would indicate a tendency for it being an ideal trade off candidate. These results could be explained by examining the actual survey group utilized to produce the data. This group consisted of active duty personnel from varying armed force services. As such, they are more concerned with user driven performance of a system vice engineers who stress the technical impacts or developmental potential of that system. The placement of emphasis on these attributes will contribute to the creation of a weighted ranking in the following section.

	Capacity	Flexibility	Information Timeliness	Maturity	Relative Cost	Reliability	Reporting & Tasking	Standardization	Survivability	Technical Risk	Training
Capacity	0.0893	0.0909	0.0833	0.0952	0.0923	0.093	0.0909	0.0847	0.0851	0.1017	0.0893
Flexibility	0.1071	0.0909	0.0833	0.0952	0.0923	0.093	0.0909	0.0847	0.1064	0.0847	0.0893
Information Timeliness	0.1071	0.1091	0.1042	0.0952	0.1077	0.093	0.0909	0.1017	0.1064	0.1017	0.1071
Maturity	0.0714	0.0727	0.833	0.0794	0.0769	0.093	0.0727	0.0847	0.0638	0.0847	0.0714
Relative Cost	0.0714	0.0727	0.0625	0.0794	0.0769	0.0698	0.0727	0.0847	0.0638	0.0847	0.0714
Reliability	0.1071	0.1091	0.125	0.0952	0.1077	0.1163	0.1273	0.1186	0.1064	0.1017	0.1071
Reporting & Tasking	0.0893	0.0909	0.1042	0.0952	0.0923	0.0698	0.0909	0.0847	0.1064	0.0847	0.0893
Standardization	0.0893	0.0909	0.0833	0.0794	0.0769	0.0698	0.0909	0.0847	0.0851	0.0847	0.0893
Survivability	0.1071	0.0909	0.1042	0.111	0.1077	0.1163	0.0909	0.1017	0.1064	0.1017	0.1071
Technical Risk	0.0714	0.0909	0.0833	0.0794	0.0769	0.093	0.0909	0.0847	0.0851	0.0847	0.0893
Training	0.0893	0.0909	0.0833	0.0952	0.0923	0.093	0.0909	0.0847	0.0851	0.0847	0.0893

	Capacity	Flexibility	Information Timeliness	Maturity	Relative Cost	Reliability	Reporting & Tasking	Standardization	Survivability	Technical Risk	Training
Mean	0.0901	0.0925	0.1022	0.0776	0.0736	0.111	0.0907	0.084	0.1041	0.0845	0.089

Table 6, The Normalized Relative Significance of TT&C Drivers

D. DEVELOPMENT OF A WEIGHTED RANKING

The conclusion of this process entails the development of the weighted ranking of the proposed candidates. This becomes the essential decision tool that can be graphically represented in a table format for the decision maker. This involves multiplying the unweighted ranking values of the decision alternatives with the mean relative significance values of individual criteria's (i.e. system / performance drivers). To continue with the illustrated example, the unweighted values from Table 3 and the mean values located in Table 5 were computed as per the above procedure. The result being the formation of weighted values which are presented in Table 7, The Weighted Ranking. Simply adding the values in each column results in each architectures weighted score. The weighted ranking is determined by numerical ranking of the individual scores. This means that the highest weighting score ranks first, the lowest score would rank last and all others fall somewhere between.

The weighted ranking displayed in Table 7 shows the preferred candidate architecture to be NAVSOC, followed by MCC and AFSCN, respectfully. This matches the results found in Table 3 which were developed with the equal weighted ranking as a first approximation. It should be noted that what has been presented is an illustrated example. A more diverse survey group could possibly achieve a different conclusion. Even with this survey group the resulting value that separated first and second place candidates was a mere 0.0856 .

TT&C Drivers	AFSCN	MCC	NAVSOC
Capacity	0.0901	0.0901	0.0901
Flexibility	0.0925	0.185	0.2775
Information Timeliness	0.2044	0.2044	0.2044
Maturity	0.2328	0.2328	0.2328
Relative Cost	0.2208	0.1472	0.1472
Reliability	0.111	0.333	0.222
Reporting & Tasking	0.0907	0.1814	0.1814
Standardization	0.084	0.168	0.168
Survivability	0.1041	0.1041	0.2082
Technical Risk	0.2535	0.169	0.169
Training	0.089	0.178	0.178
Weighted Score	1.5728	1.993	2.0786
Weighted Ranking	3	2	1

Table 7, Weighted Ranking of TT&C Architectures

E. EVALUATION OF THE COST HIERARCHY

The decision maker's ability to choose a proposed decision alternative is motivated not only by performance but cost concerns. The final stage in AHP instructs the decision maker to weigh performance versus cost of each candidate. The previous sections gave the decision maker the ability to grade an architectures performance. It is essential to understand that there exists a cost for that associated performance level. To aid in a cost analysis of TT&C architectures, a cost hierarchy model was developed. This model stresses specific areas where significant cost is incurred within any given architecture. Figure 13, The Cost Analysis Model, indicates four major areas determined by the authors to be essential. The majority of cost in an architecture occurs during its development, setup and production, and its continued operations and maintenance. It is also important to note that unforeseen cost will occur and the model provides for this in an area labeled *Uncertainty*.

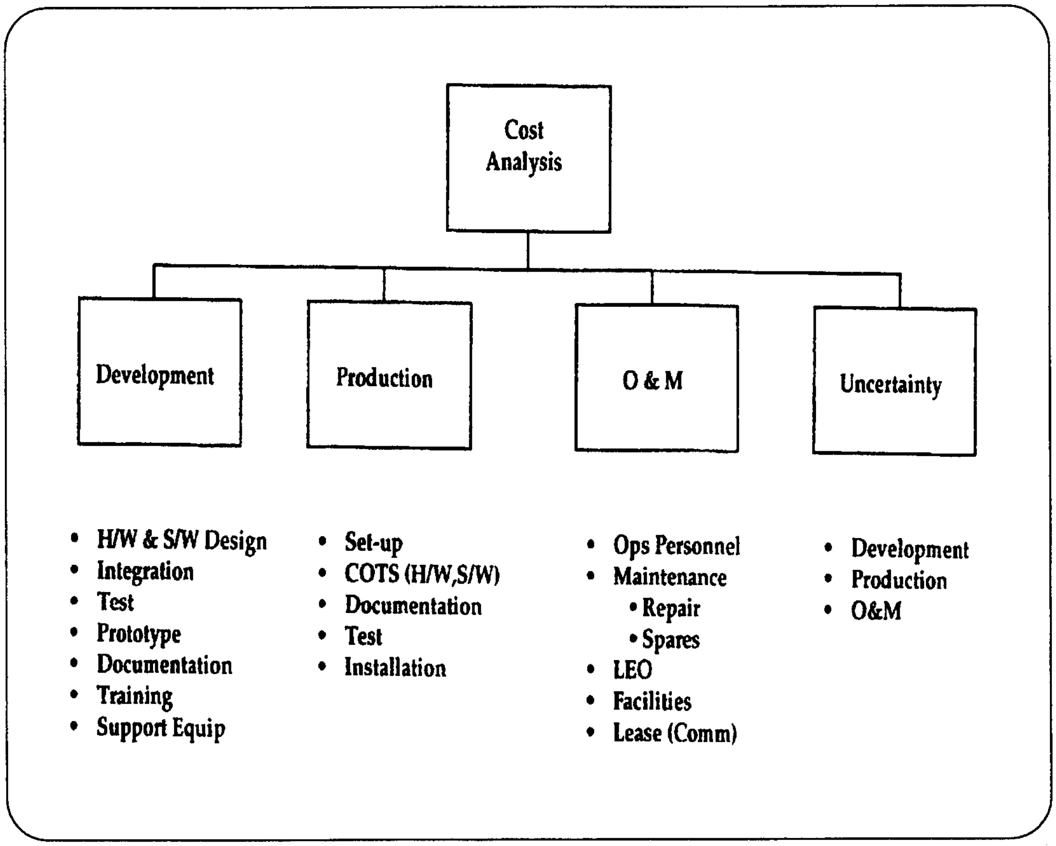


Figure 13, The Cost Analysis Model

F. SUMMARY

The methodology presented in this chapter provides the decision maker with an objective approach to evaluate potential future as well as current TT&C architectures. An illustrated example was provided with each step to aid in clarification of the procedures involved. The chapter also gave a brief insight into the cost analysis model associated with TT&C environment. Coupled with the information contained in Chapters II and III, a foundation has been established which will provide a substantial aid in any future decisions concerning TT&C architectures.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The intention of the authors was to focus the research into a format usable by a decision maker to aid in the selection of future TT&C architectures. As can be seen in the layout of the chapters, this was achieved through four distinct steps. These steps act as a capable aid by providing the following: better understanding of the process involved in TT&C; knowledge of what is available by identification of current architectures; comprehension of developing trends which will be seen in the proposed candidates; and demonstration of an objective methodology which can be used for evaluation.

1. The TT&C Process

In Chapter II, the first step in aiding the decision maker was accomplished by a descriptive illustration of the TT&C process. A better understanding would provide a foundation capable of allowing a more informed decision. The authors were able to identify and illustrate the interrelationships of primary and associated functions as they pertain to a generic TT&C architecture.

2. Current Architectures

The goal of the second step was to inform the decision maker of current TT&C architectures. Chapter III reviewed three of these architectures: Air Force Satellite Control Network (AFSCN), Mission Control Center (MCC), and Naval Satellite Operations Center (NAVSOC). The architectures chosen represented varying methods of conducting TT&C.

3. Trends In TT&C Architectures

In addition, Chapter III highlighted the trends in TT&C architecture development based on DOD policies and existing architectures. This third step would alert those involved in the evaluation process to what TT&C developments can be expected or

required in future proposals. The following trends were identified and should be regarded for future developing architectures:

(1) automation

(2) Commercial Off The Shelf (COTS)

(3) distributed systems

(4) open architectures

(5) plug-in-use

(6) graphic operator interfaces

(7) use of the Open System Interconnection (OSI) Model

4. The Methodology and Illustration

The last step focused on providing a method for objective evaluation of TT&C architectures. Through discussions in Chapter IV, critical performance and system drivers were identified. The Analytic Hierarchy Process (AHP), an evaluation tool, was then applied. To aid in the comprehension of how AHP appplies, an illustrative example was provided. The example utilized the AFSCN, MCC, and the NAVSOC architectures that were described in Chapter III.

B. CONCLUSIONS

The authors offer the decision maker an alternative approach in evaluating current and future TT&C architectures. The benefit of their proposed methodology lies in its ability to be applied to architectures of varying design and complexity. Developing TT&C systems will take advantage of new state-of-the-art technologies. It is this technology evolution that the methodology specifically addresses.

This method is presented in its most basic form. It has the potential for further growth. As new drivers or trends are realized, it is a simple process to incorporate them and achieve meaningful results. The authors note that a thorough cost analysis of candidate TT&C architectures should be performed in conjunction with the use of this methodology. This would provide a complete cost and operational effectivness analysis (COEA).

C. RECOMMENDATIONS

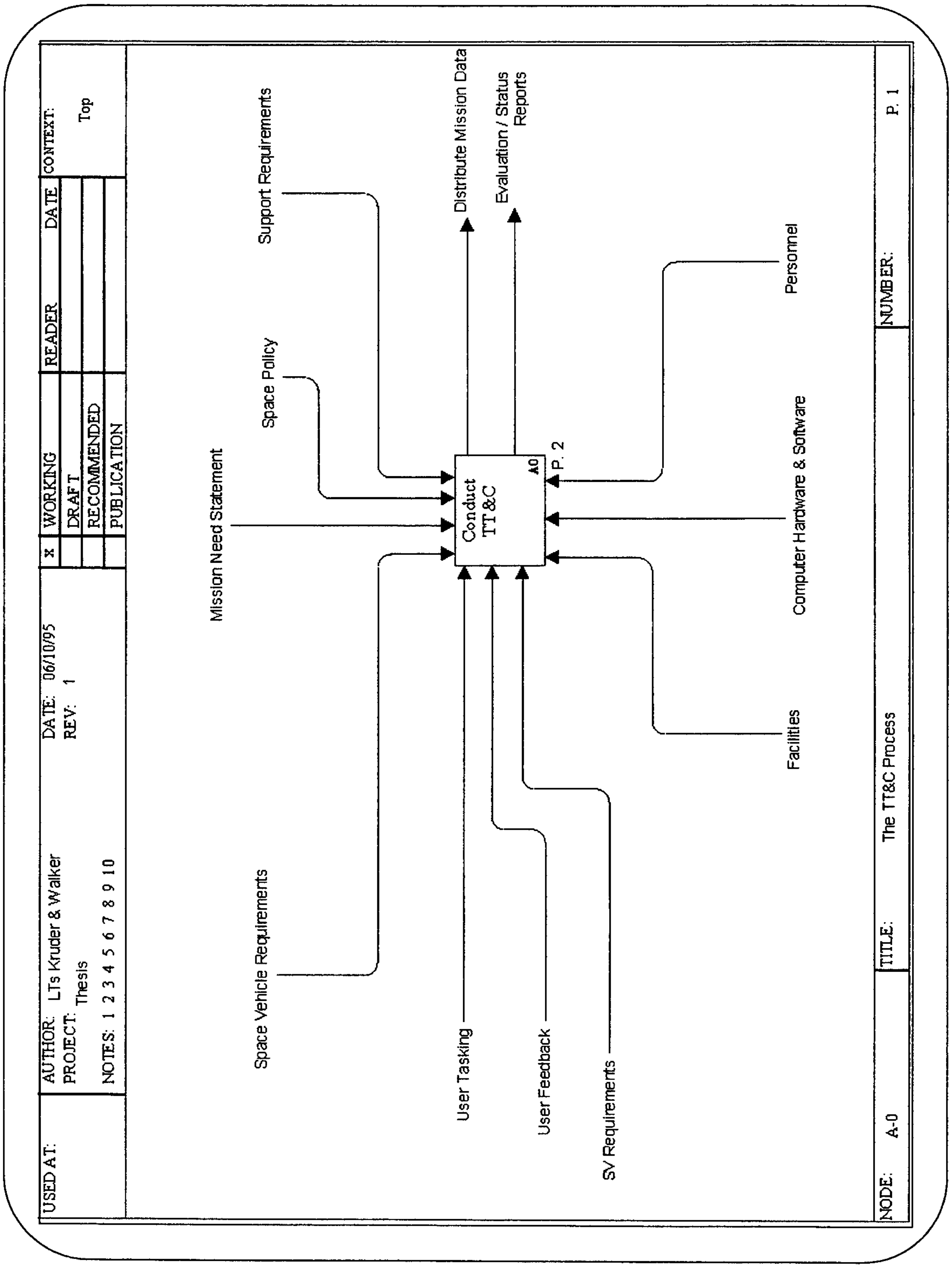
The methodology presented in this thesis represents the first prototype of an objective tool for evaluating alternative TT&C architectures. It is the authors opinion that there exist multiple areas that could be further expanded. The most obvious areas include the following:

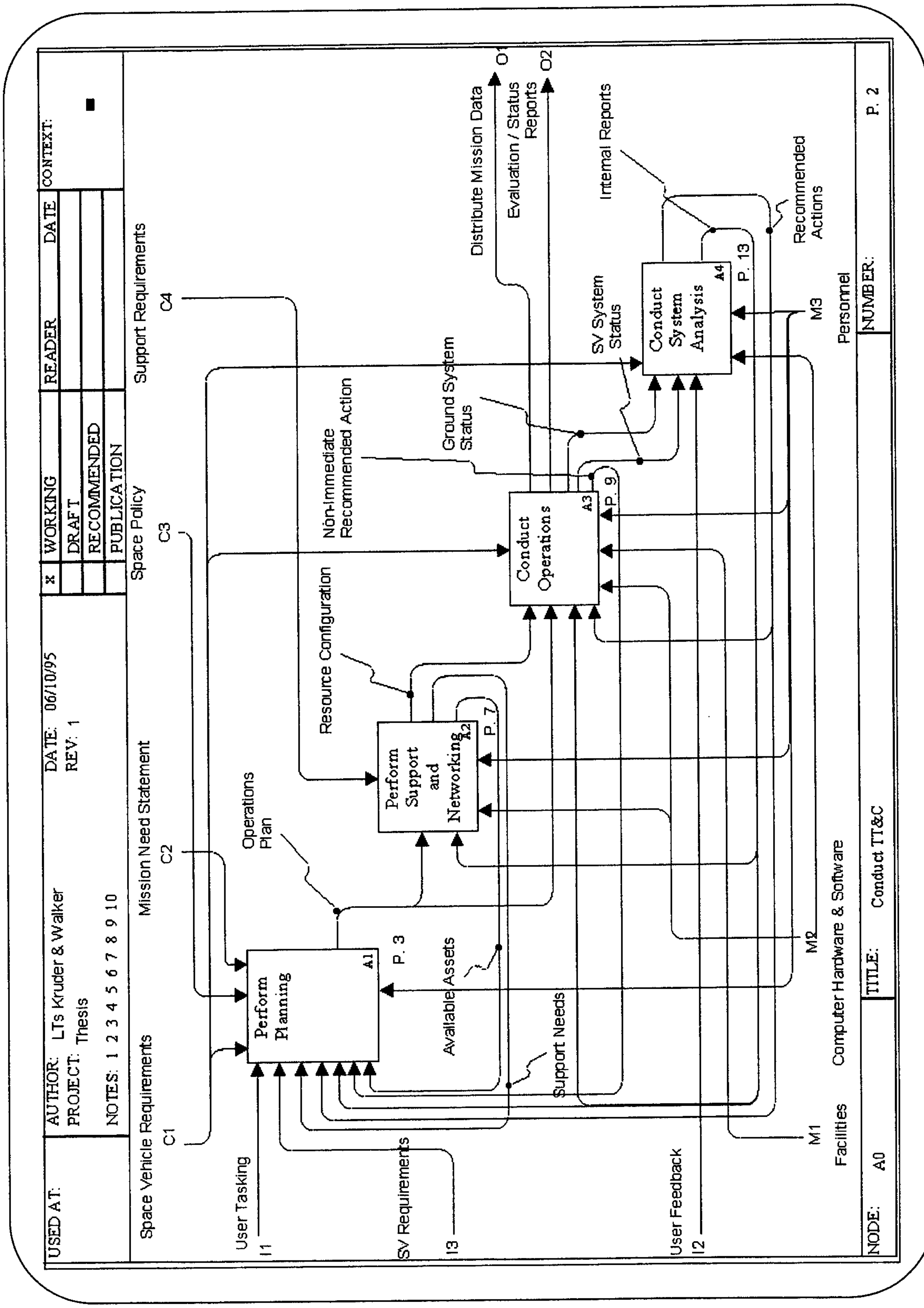
(1) Further development of the TT&C process model to include additional analysis of lower levels associated with sub-functions already presented.

(2) Development of a thorough cost modeling hierarchy for a generic TT&C architecture.

(3) Conduct additional surveys with technical experts as well as other users concerned with TT&C development for the purpose of validating the method proposed in this thesis.

APPENDIX A. TT&C PROCESS SYSTEM ANALYSIS DIAGRAMS

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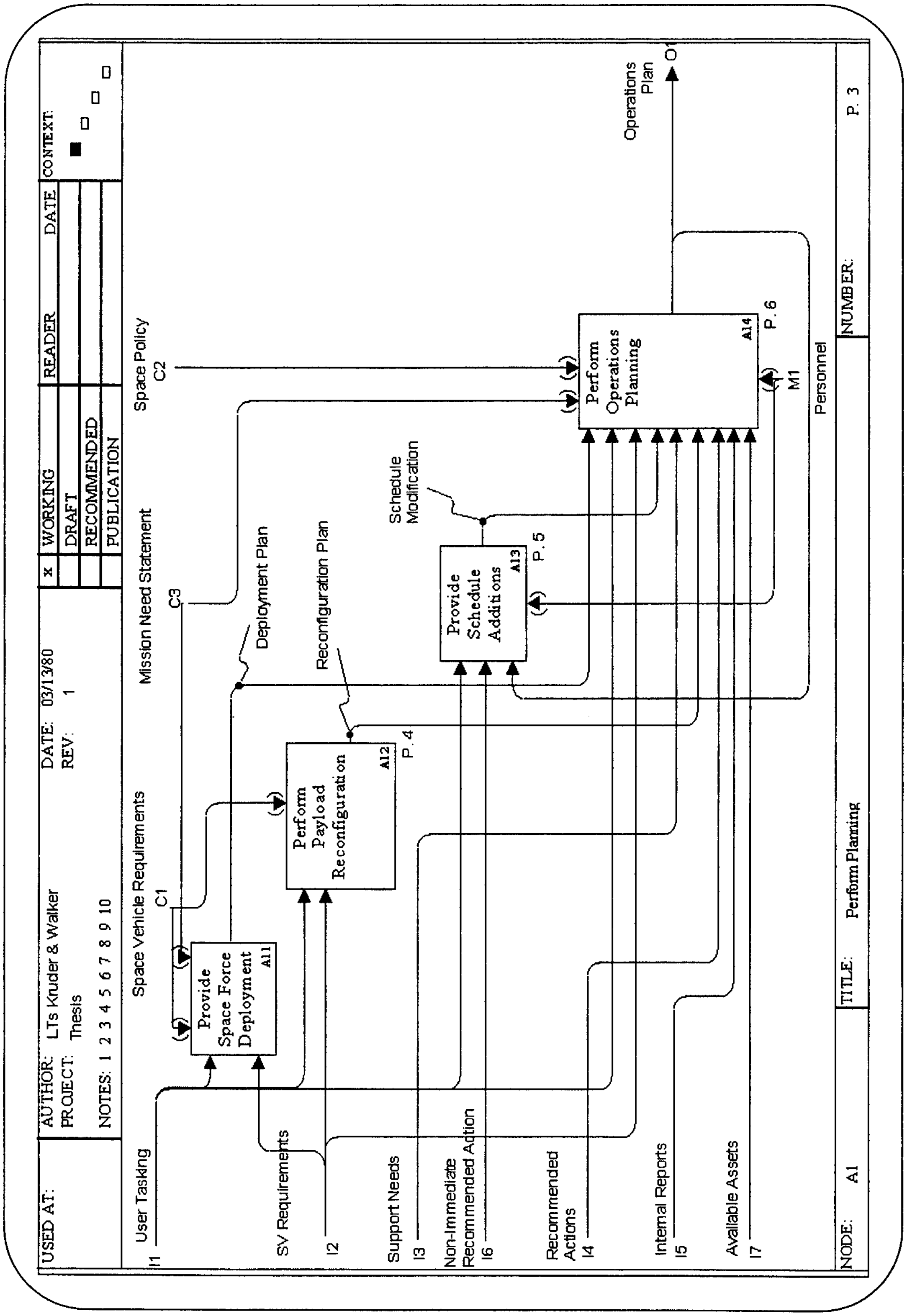
C1
Mission Need Statement
C2
Space Policy
C3
Support Requirements
C4
User Tasking
I1
SV Requirements
I3
User Feedback
I2
Perform Planning
A1
P. 3
Operations Plan
Available Assets
Support Needs
Perform Support and Networking
A2
P. 7
Resource Configuration
Conduct Operations
A3
P. 9
Non-Immediate Recommended Action
Ground System Status
SV System Status
Conduct System Analysis
A4
P. 13
Distribute Mission Data
O1
Evaluation / Status Reports
O2
Internal Reports
Recommended Actions
M1
Facilities
M2
Computer Hardware & Software
M3
Personnel
NODE: A0
TITLE: Conduct TT&C
NUMBER:
P. 2



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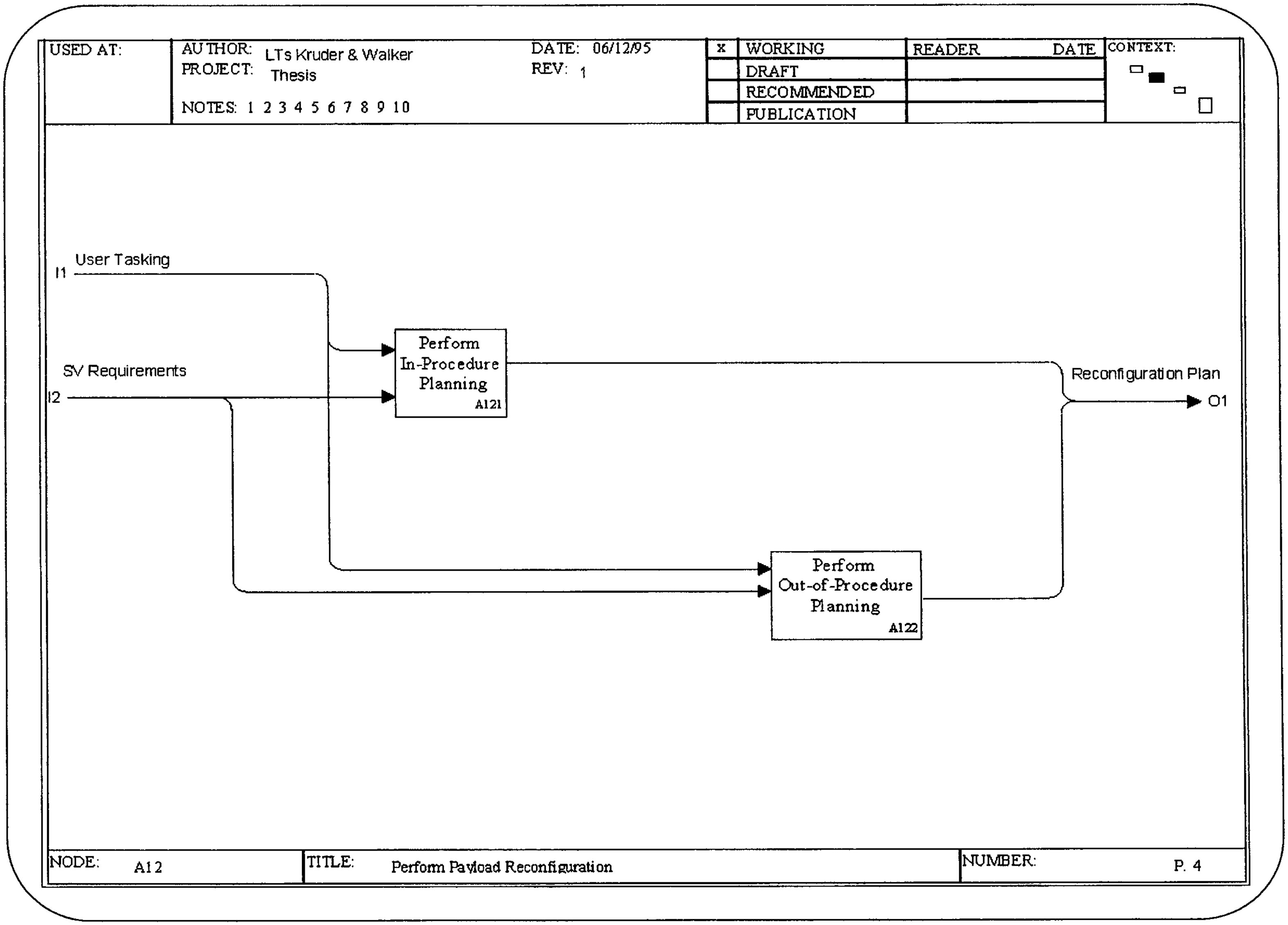
Space Vehicle Requirements
C1
Mission Need Statement
C3
Space Policy
C2
Provide Space Force Deployment
A11
Perform Payload Reconfiguration
A12
P. 4
Provide Schedule Additions
A13
P. 5
Perform Operations Planning
A14
P. 6
Deployment Plan
Reconfiguration Plan
Schedule Modification
Operations Plan
O1
M1
Personnel
User Tasking
I1
SV Requirements
I2
Support Needs
I3
Non-Immediate Recommended Action
I6
Recommended Actions
I4
Internal Reports
I5
Available Assets
I7
NODE: A1
TITLE: Perform Planning
NUMBER:
P. 3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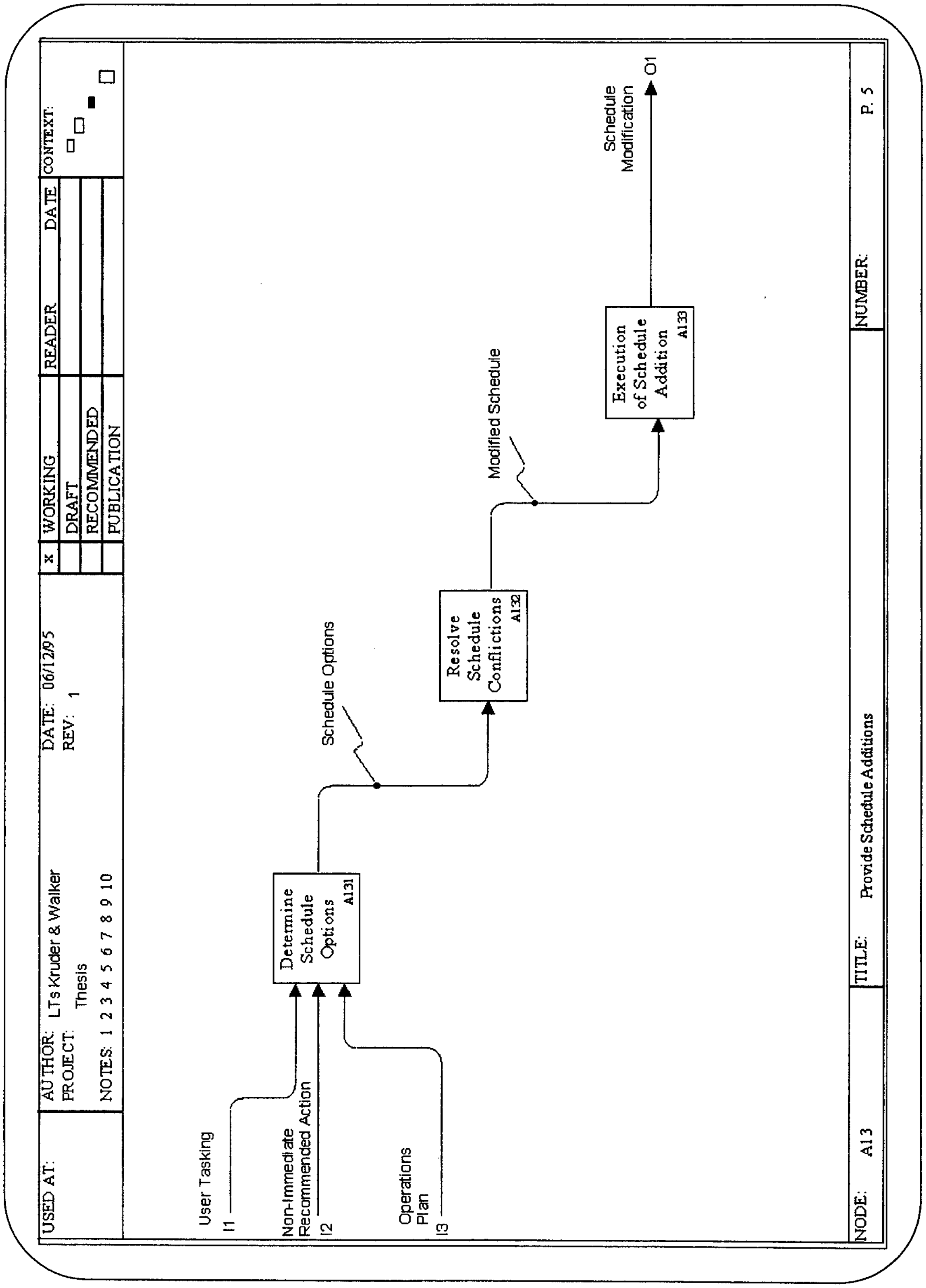
I1 User Tasking
I2 SV Requirements
Perform In-Procedure Planning
A121
Perform Out-of-Procedure Planning
A122
Reconfiguration Plan
O1
NODE: A12
TITLE: Perform Payload Reconfiguration
NUMBER: P. 4



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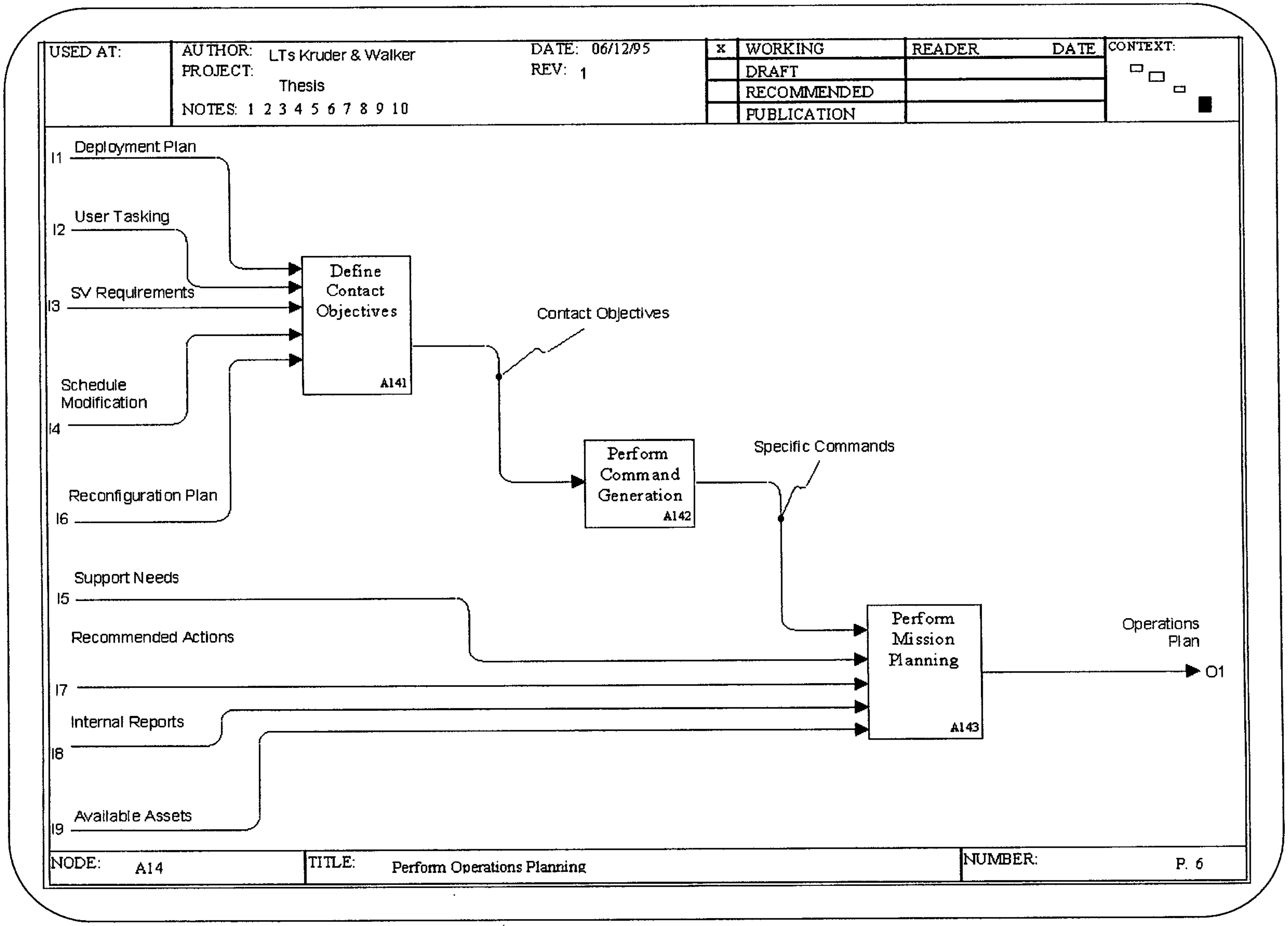
User Tasking
I1
Non-Immediate Recommended Action
I2
Operations Plan
I3
Determine Schedule Options
A131
Schedule Options
Resolve Schedule Conflictions
A132
Modified Schedule
Execution of Schedule Addition
A133
Schedule Modification
O1
NODE: A13
TITLE: Provide Schedule Additions
NUMBER: P. 5



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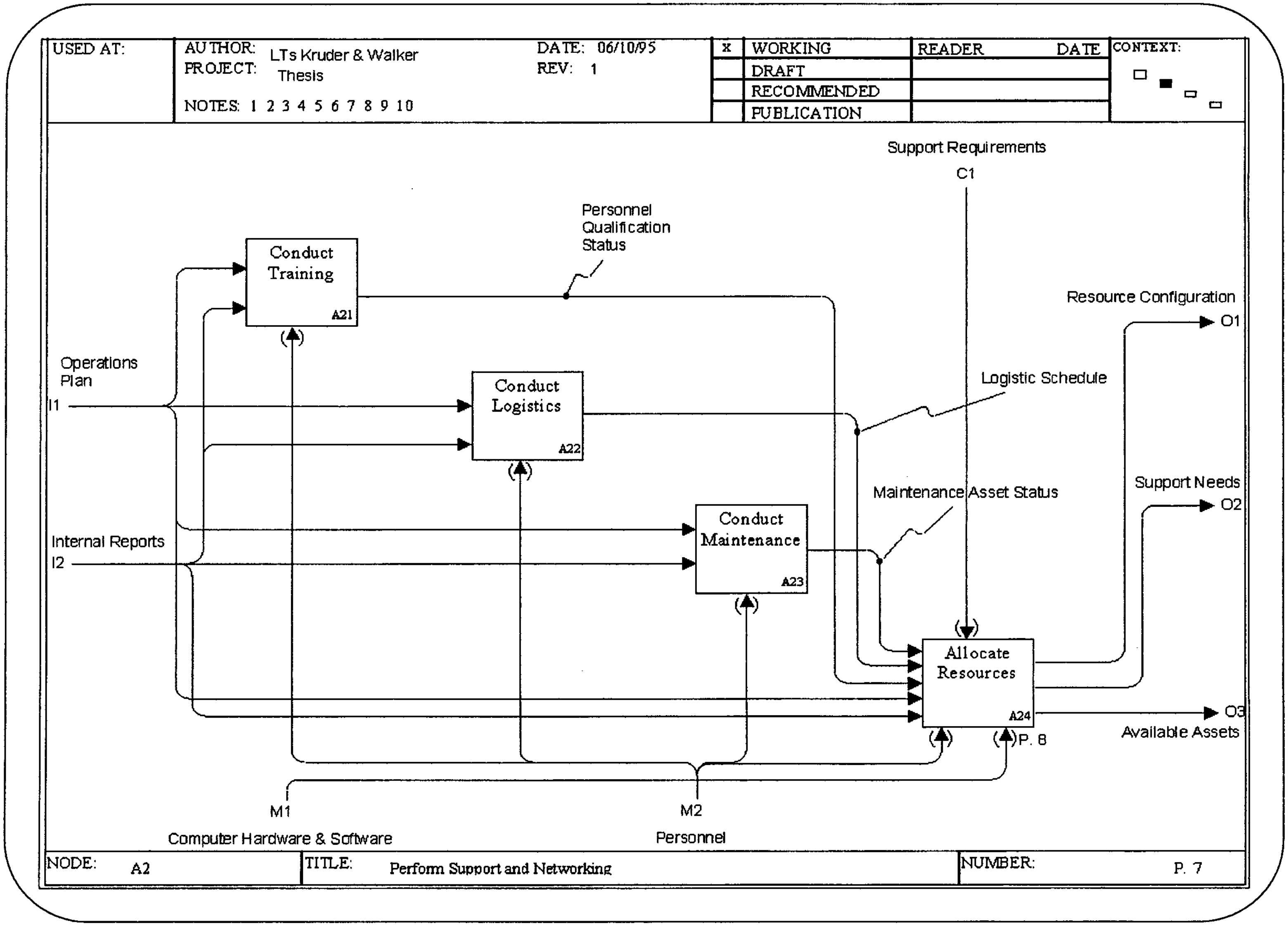
I1 Deployment Plan
I2 User Tasking
I3 SV Requirements
Schedule Modification
I4
Reconfiguration Plan
I6
Support Needs
I5
Recommended Actions
I7
Internal Reports
I8
Available Assets
I9
Define Contact Objectives
A141
Contact Objectives
Perform Command Generation
A142
Specific Commands
Perform Mission Planning
A143
Operations Plan
O1
NODE: A14
TITLE: Perform Operations Planning
NUMBER: P. 6



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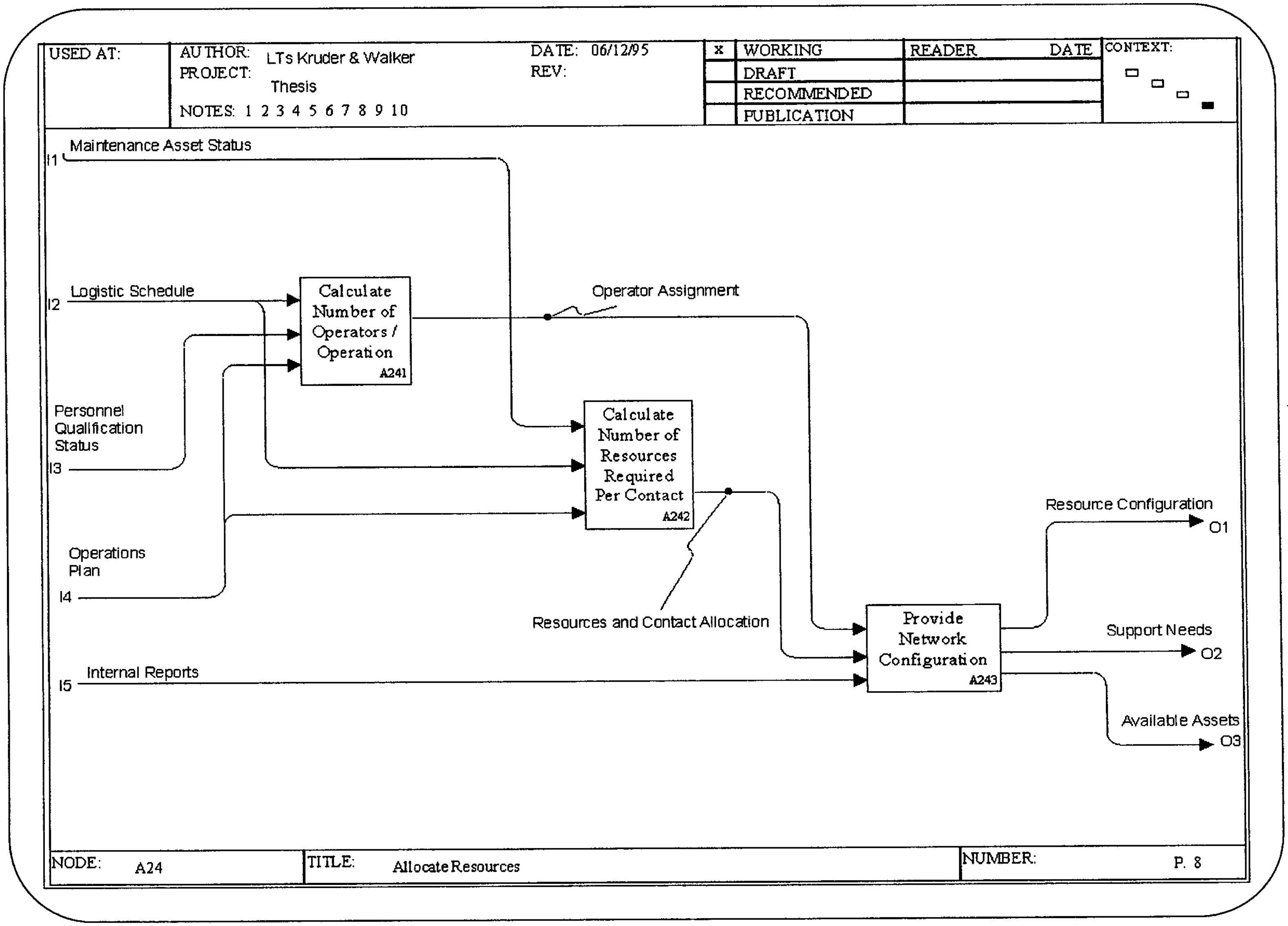
Support Requirements
C1
Personnel Qualification Status
Conduct Training
A21
Operations Plan
I1
Conduct Logistics
A22
Logistic Schedule
Resource Configuration
O1
Internal Reports
I2
Conduct Maintenance
A23
Maintenance Asset Status
Support Needs
O2
Allocate Resources
A24
O3
Available Assets
P. 8
M1
Computer Hardware & Software
M2
Personnel
NODE: A2
TITLE: Perform Support and Networking
NUMBER: P. 7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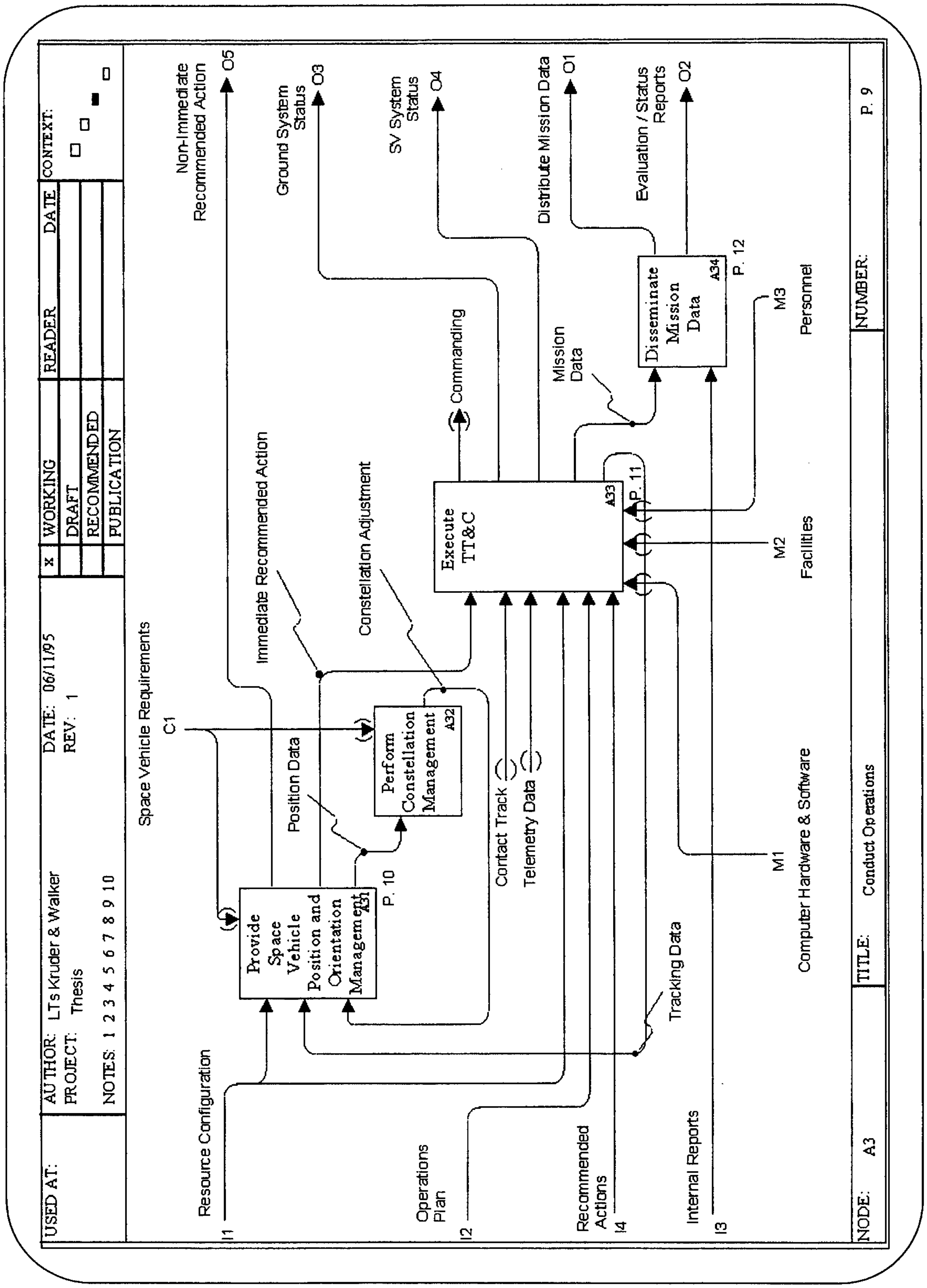
CONTEXT:
I1 Maintenance Asset Status
I2 Logistic Schedule
I3 Personnel Qualification Status
I4 Operations Plan
I5 Internal Reports
Calculate Number of Operators / Operation
A241
Operator Assignment
Calculate Number of Resources Required Per Contact
A242
Resources and Contact Allocation
Provide Network Configuration
A243
Resource Configuration
O1
Support Needs
O2
Available Assets
O3
NODE: A24
TITLE: Allocate Resources
NUMBER: P. 8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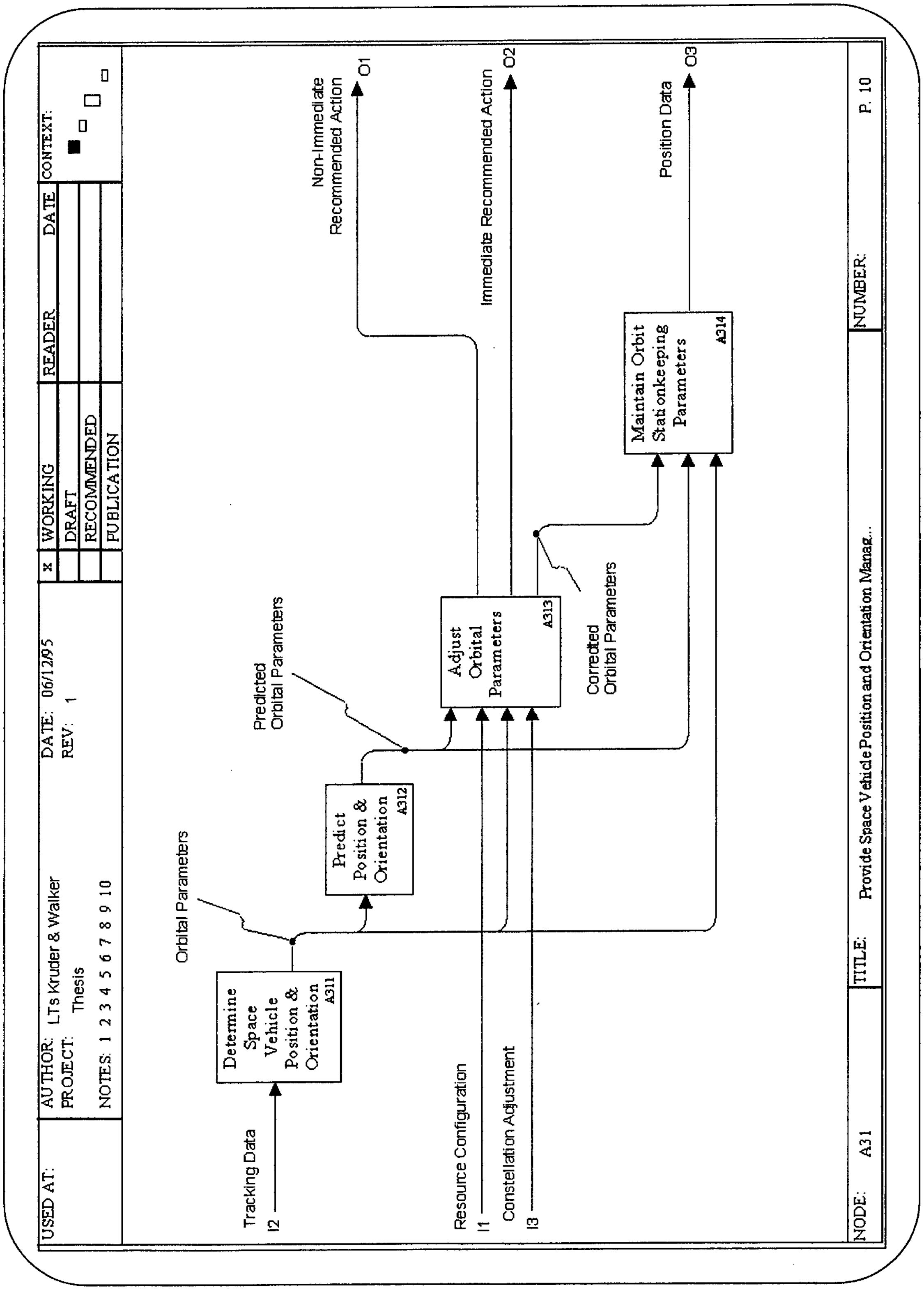
CONTEXT:
Space Vehicle Requirements
C1
Resource Configuration
I1
Operations Plan
I2
Recommended Actions
I4
Internal Reports
I3
Provide Space Vehicle Position and Orientation Management
A31
P. 10
Perform Constellation Management
A32
Execute TT&C
A33
P. 11
Disseminate Mission Data
A34
P. 12
Position Data
Immediate Recommended Action
Constellation Adjustment
Contact Track
Telemetry Data
Tracking Data
Commanding
Mission Data
Non-Immediate Recommended Action
O5
Ground System Status
O3
SV System Status
O4
Distribute Mission Data
O1
Evaluation / Status Reports
O2
M1
Computer Hardware & Software
M2
Facilities
M3
Personnel
NODE: A3
TITLE: Conduct Operations
NUMBER: P. 9



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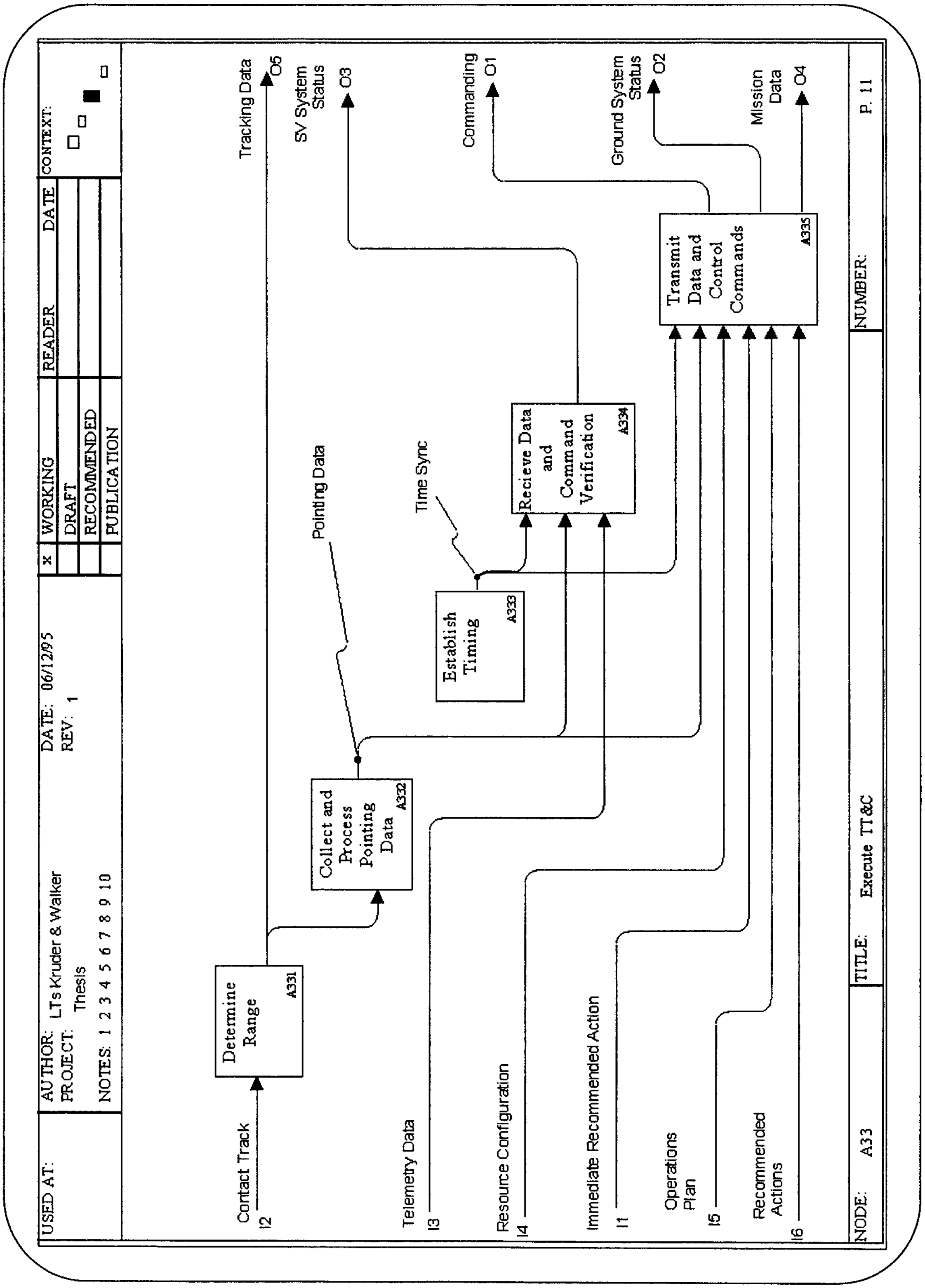
READER
DATE
CONTEXT:
Tracking Data
I2
Determine Space Vehicle Position & Orientation
A311
Orbital Parameters
Predict Position & Orientation
A312
Predicted Orbital Parameters
Adjust Orbital Parameters
A313
Corrected Orbital Parameters
Maintain Orbit Stationkeeping Parameters
A314
Resource Configuration
I1
Constellation Adjustment
I3
Non-Immediate Recommended Action
O1
Immediate Recommended Action
O2
Position Data
O3
NODE: A31
TITLE: Provide Space Vehicle Position and Orientation Manag...
NUMBER: P. 10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DATE: 06/12/95
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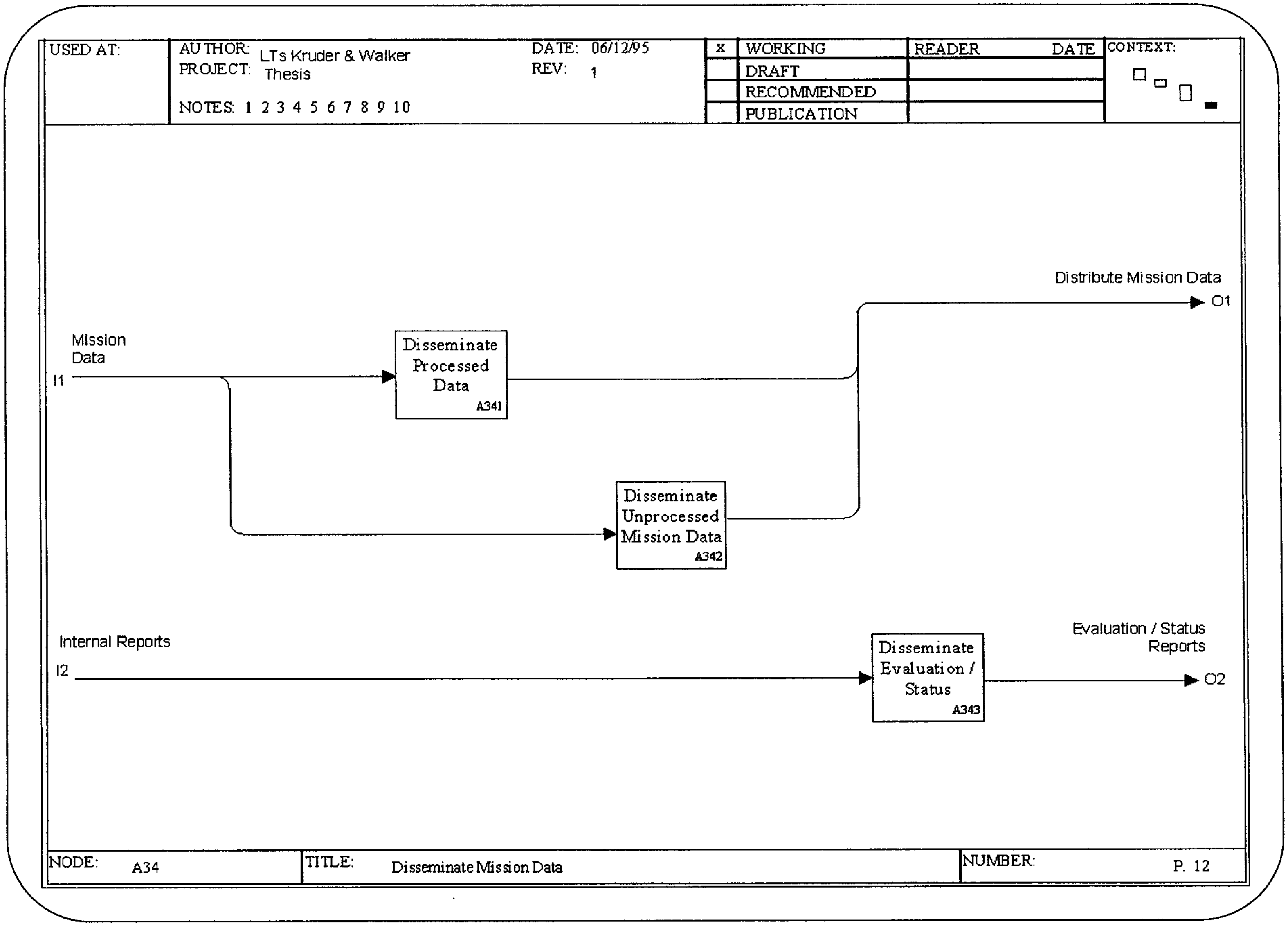
PUBLICATION
READER
DATE
CONTEXT:
Contact Track
I2
Telemetry Data
I3
Resource Configuration
I4
Immediate Recommended Action
I1
Operations Plan
I5
Recommended Actions
I6
Determine Range
A331
Collect and Process Pointing Data
A332
Pointing Data
Establish Timing
A333
Time Sync
Recieve Data and Command Verification
A334
Transmit Data and Control Commands
A335
Tracking Data
O5
SV System Status
O3
Commanding
O1
Ground System Status
O2
Mission Data
O4
NODE: A33
TITLE: Execute TT&C
NUMBER:
P. 11



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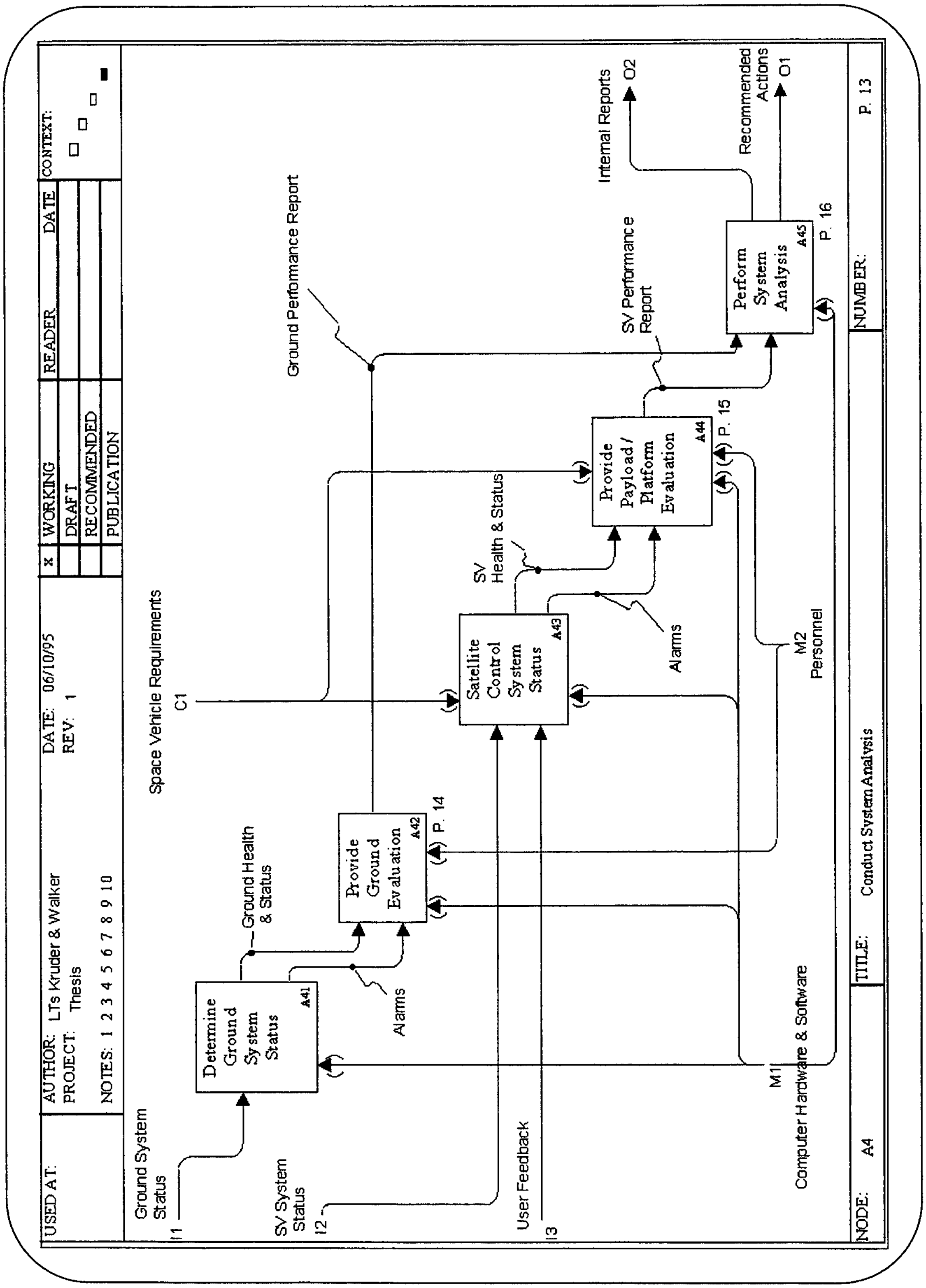
DATE
CONTEXT:
Mission Data
I1
Disseminate Processed Data
A341
Disseminate Unprocessed Mission Data
A342
Distribute Mission Data
O1
Internal Reports
I2
Disseminate Evaluation / Status
A343
Evaluation / Status Reports
O2
NODE: A34
TITLE: Disseminate Mission Data
NUMBER: P. 12



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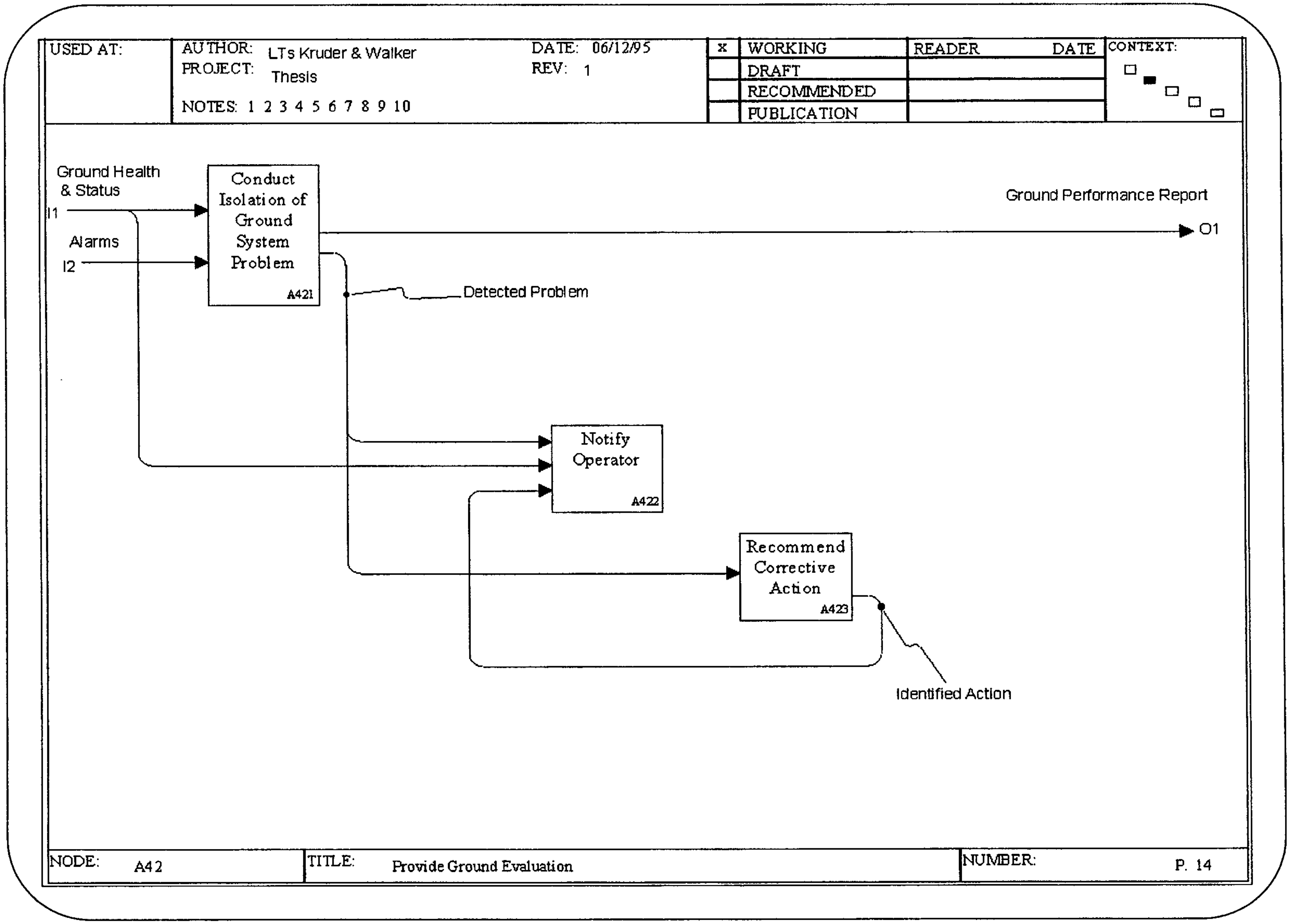
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
I1 Ground System Status
I2 SV System Status
I3 User Feedback
C1 Space Vehicle Requirements
M1 Computer Hardware & Software
M2 Personnel
Determine Ground System Status A41
Ground Health & Status
Alarms
Provide Ground Evaluation A42
P. 14
Ground Performance Report
Satellite Control System Status A43
SV Health & Status
Alarms
Provide Payload / Platform Evaluation A44
P. 15
SV Performance Report
Perform System Analysis A45
P. 16
Internal Reports O2
Recommended Actions O1
NODE: A4
TITLE: Conduct System Analysis
NUMBER: P. 13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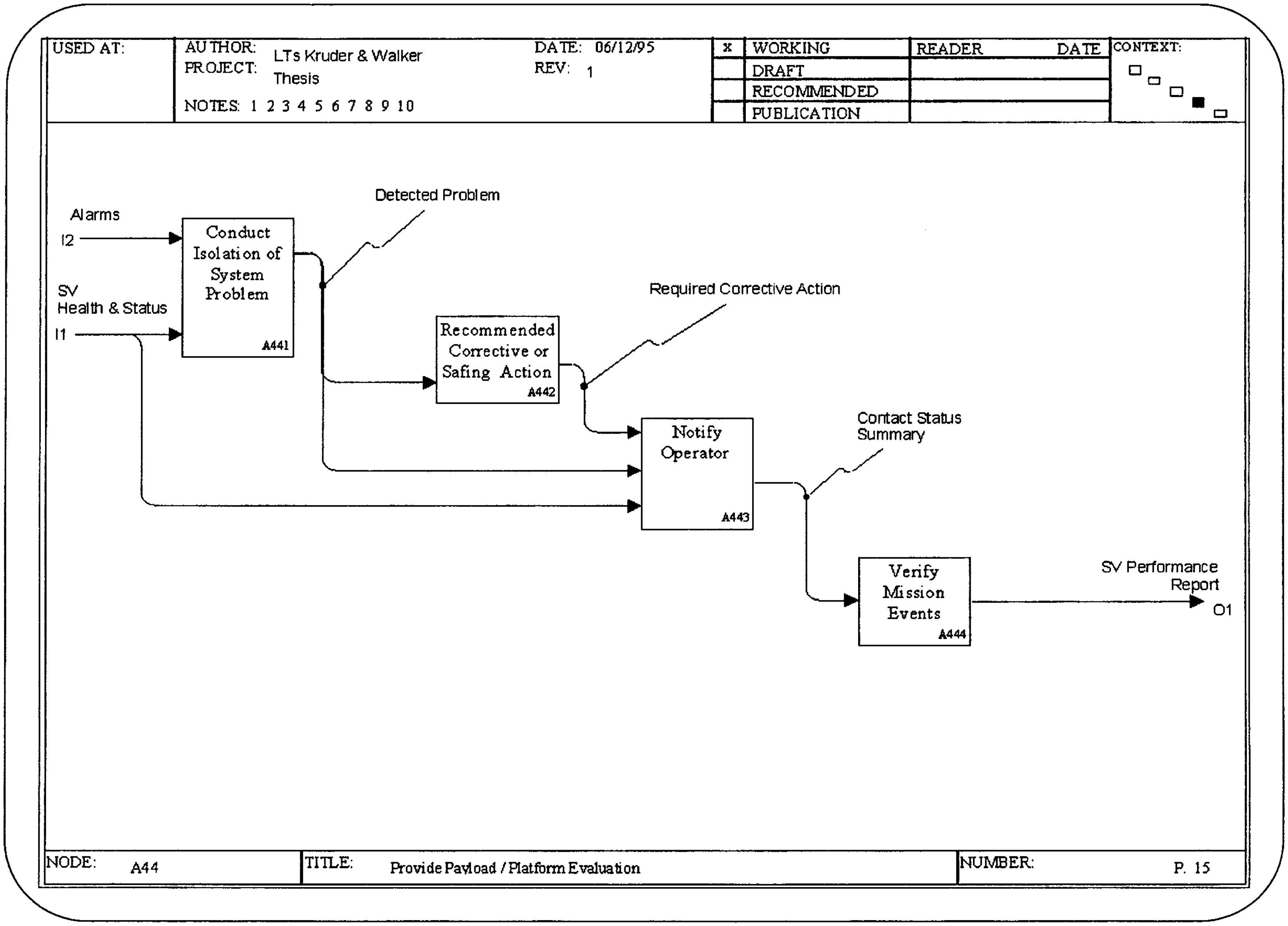
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
Ground Health & Status
I1
Alarms
I2
Conduct Isolation of Ground System Problem
A421
Ground Performance Report
O1
Detected Problem
Notify Operator
A422
Recommend Corrective Action
A423
Identified Action
NODE: A42
TITLE: Provide Ground Evaluation
NUMBER: P. 14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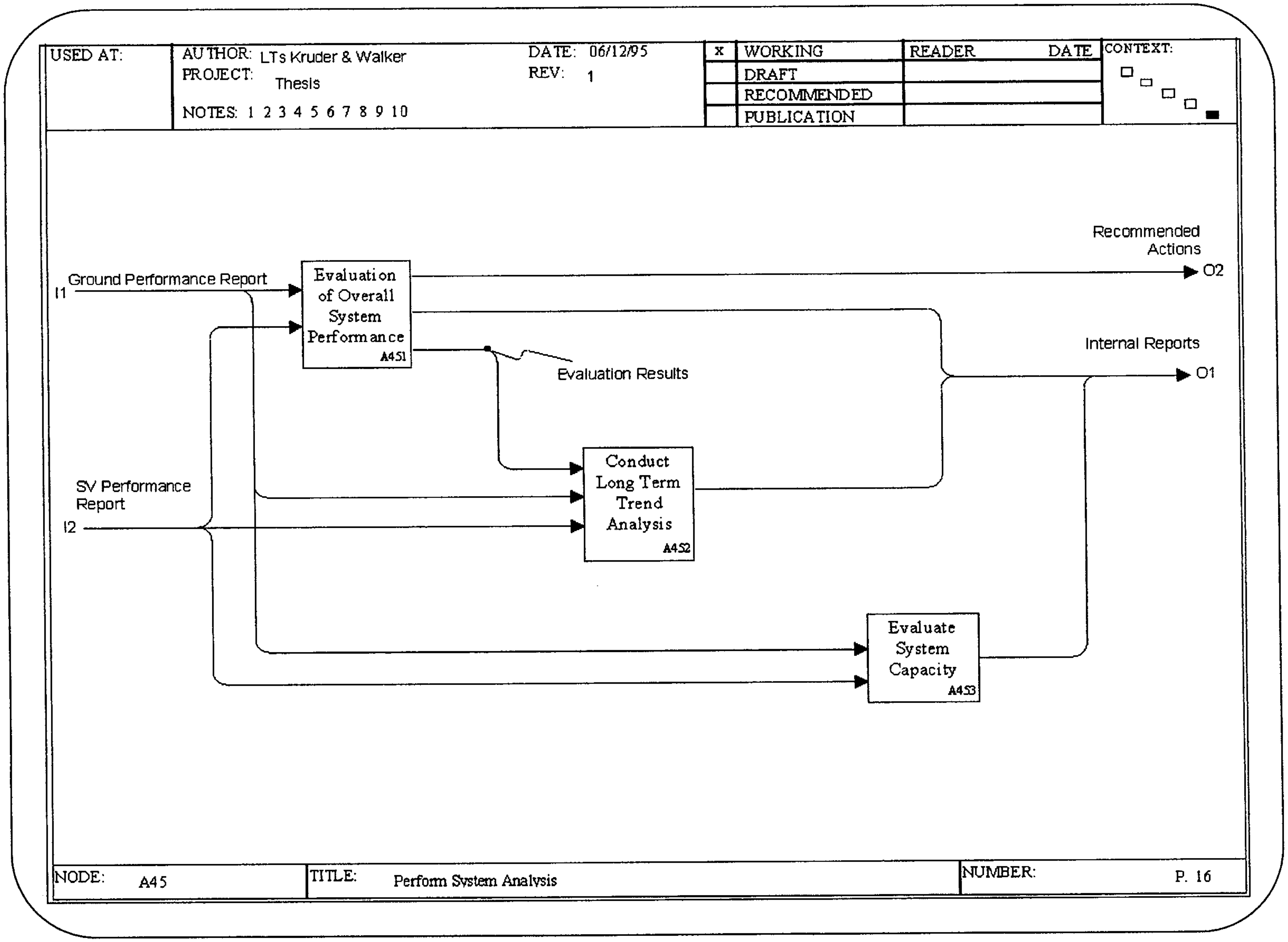
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
Alarms
I2
SV
Health & Status
I1
Conduct Isolation of System Problem
A441
Detected Problem
Recommended Corrective or Safing Action
A442
Required Corrective Action
Notify Operator
A443
Contact Status Summary
Verify Mission Events
A444
SV Performance Report
O1
NODE: A44
TITLE: Provide Payload / Platform Evaluation
NUMBER: P. 15



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DATE: 06/12/95
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RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
Ground Performance Report
I1
SV Performance Report
I2
Evaluation of Overall System Performance
A451
Evaluation Results
Conduct Long Term Trend Analysis
A452
Evaluate System Capacity
A453
Recommended Actions
O2
Internal Reports
O1
NODE: A45
TITLE: Perform System Analysis
NUMBER:
P. 16

APPENDIX B. DATA DEFINITIONS

Alarms: Pre - programmed indicators which detect adverse anomalies that exceed established space vehicle and/or ground facility limitations.

Available Assets: A list of current status and availability of resources allocated to the TT&C facility which can be utilized for future planning.

Commanding: This is the uplink information required to instruct a SV for the purpose of controlling mission execution or maintaining operability. This information typically includes synchronization code, spacecraft address bits, command message bits , and error check bits.

Computer Hardware & Software: Advanced computational equipment and associated software required to carry out such activities as scheduling, analysis, evaluation and system simulations.

Constellation Adjustment: Requirements, based on current constellation coverage, used to formulate recommended actions to ensure maintaining a specified mission coverage.

Contact Objectives: Commanding objectives, in order of priority, desired to be formulated into command code and sent during establishment of communication lock between SV and ground facility.

Contact Status Summary: A descriptive summary of actions taken during a mission contact phase.

Contact Track: The initial establishment of a lock-on between a space vehicle and its ground facility's tracking network.

Deployment Plan: A generated order of tasking requirements for a specific space force deployment. Included in this plan would be the following: support pre-launch preparations, launch support, early orbit check out, positioning of space assets on - orbit, request for data, movement of spares, and repositioning for coverage.

Detected Problem: Identification of an observed malfunction or abnormality discovered in either the SV and/or component of the ground segment.

Distributed Mission Data: Mission essential data in the final format desired by the original tasking user.

Facilities: Those structures that directly contribute supportive roles necessary for successful TT&C. Examples range from remote antenna sites, training classrooms, administration buildings and maintenance shops.

Evaluation Results: Specific outcome of an overall system performance evaluation concerning a SV and the supporting ground segment.

Evaluation / Status Reports: An external report generated for dissemination to outside commands and non-DOD users. Information contained may include position and current status of mission SV and their control assets.

Ground Health & Status: Specific data that is queried from participating ground facilities that contribute in determining the current Health and Status of the ground segment.

Ground Performance Report: Pertinent ground segment information which would be used in analysis of overall performance.

Ground System Status: A list of the current states of critical system components and associated parameters.

Identified Action: The corrective actions presented to an operator as a recommendation in response to a detected problem.

Internal Reports: A series of in-house generated reports essential for smooth operations within a TT&C facility. Possible examples include: Capacity Management Report, which graphically represents current network loading and utilization data and compares it with the theoretical capacity modeling, Ground Segment Evaluation Report, and SV System Evaluation Report.

Immediate Recommended Actions: These are tasks to an operator to perform specified routines to accomplish a necessary action or in response to an identified problem. These actions are associated with time sensitive requirements that cannot be satisfied through the normal scheduling or schedule addition process.

Logistic Schedule: Outlines the use of supporting elements of a non - flight essential nature after receiving initial requests for specific material resources and support to assist in completion of scheduled maintenance.

Maintenance Asset Status: Indicator of ground segment hardware and software status. Includes operator workstations, processors, software, and simulators.

Mission Data: Data taken from the downlinked telemetry stream which is mission specific.

Mission Need Statement (MNS): SV specific, the MNS details qualitative mission objectives which the SV must achieve to be useful to the user/warfighter.

Modified Schedule: The result of scheduling deconflictions used in formulating a schedule modification.

Non-immediate Recommended Actions: These are tasks to an operator to perform specified routines to accomplish a necessary action or in response to an identified problem. The actions can be satisfied through the normal scheduling or schedule addition process.

Operations Plan: The compilation of all plans required to properly perform TT&C. Examples would include: Mission Plan, Schedule Plan, Training Plan, and Maintenance Plan.

Operator Assignment: Operator to operation allocation.

Personnel: The human element required to accomplish all aspects of executing and supporting TT&C. Some examples would be the following: Operators, training instructors, administrators, and technicians.

Personnel Qualification Status: Represents current status of operator qualifications and the expiration date of each qualification.

Pointing Data: Information necessary to allow the tracking network to gain proper orientation to establish a reliable uplink capability.

Positioning Data: Current ephemeris data derived from the processed tracking data.

Predicted Position: Ephemeris data based on computations of a future timeline.

Recommended Actions: These are assigned tasks to an operator to perform specified routines to accomplish a necessary action or in response to an identified problem.

Reconfiguration Plan: A specific mission plan based on user and SV requirements that would initiate proper configuration of the SV.

Resource Configuration: Resources required of the SV control network in order to perform scheduled missions. This would address the Network Utilization Schedule that outlines the operator to operation tasking and network configuration assignments. In addition, all items required to ensure a successful communication connectivity throughout the space control network would be involved.

SV Health & Status: Specific data taken from the downlinked telemetry that pertains to the current health and status of a SV.

SV Performance Report: Pertinent platform / payload information which would be used in analysis of overall performance.

SV System Status: A list of the current status of critical system components and associated parameters. Specific data that contributes to the determination of the current SV health and status.

Schedule Modification: An identification of specific mission tasking required to be incorporated within the scheduling process.

Schedule Options: Consist of several schedule considerations the result of user tasking and Non - Immediate Recommended Actions.

Space Policy: Those space specific political and economic guidelines set forth by the following: Current Administration, Congress, and DOD.

Space Vehicle Requirements: Closely related to the SV MNS, SV requirements contain succinct, well-defined, critical functional and operational elements.

Specific Commands: Those commands necessary in accomplishing the pre determined contact objectives, maintaining Health & Status, and orbital orientation.

Support Needs: Contains specific supporting request for items necessary in carrying out the support functions identified mission area such as Training, Maintenance, Logistics, and Supply.

Support Requirement: Include the specific items such as, packaging, handling, transportation, depot / system technical orders, configuration control, and sparing strategies.

Telemetry Data: This is the downlinked information received by the processing center which pertains to the health, status, and mission performance of the SV. Mission related data, which was collected by the SV, is digitized and downlinked in conjunction with the previously mentioned information.

Time Sync: For support of attitude control, commanding, and time - tagging. Time sync may be supplied by either computer maintained counters or hardware timers.

Tracking Data: This is information required to precisely determine a SV location and velocity with respect to the tracking facility. The data consists of time, elevation, azimuth, range, and range rate.

User Feedback: The necessary connectivity which allows for the interface between the user / warfighter and the control system. Directly contributes to the overall quality assurance of the SV control system.

User Tasking: A request by the user / warfighter for either time critical or routine mission tasking. Possible requests include either Reconfiguration Request or Schedule Addition Request.

APPENDIX C. MCC SUPPORTING ANTENNAS

1. C - Band Antennas

Location	Description
AFFTC, EAFB, CA	FPS-16
Antigua Island	FPQ-14
Ascension Island	FPQ-15, TPQ-18
Bermuda Island	FPQ-6
Cape Canaveral, FL	MPS-39, FPS-16
DFRC, CA	FPS-16, FPD-16
Ft. Huachuca, Scott Peak, AZ	FPS-16
Jonathan Dickinson, FL	FPQ-14
Kaena Point, HI	FPQ-14
Kwajelein Island	TRADEX, ALCOR, ALTAIR, FPQ-19
Merrit Island, FL	FPQ-14, MCB-17
Mt. Lemmon, AZ	CAPRI
Patrick AFB, FL	FPQ-14
Point Mugu, CA	FPS-16, FPS-16V
Point Pillar, CA	FPQ-6, MPS-36
San Nicolas Island	FPS-16
Vandenberg AFB, CA	FPS-16, TPQ-18, HAIR
Waliops Flight Facility, VA	FPQ-6, FPS-16
White Sands, NM	FPS-16
White Sands, Stall Station, NM	FPS-16
White Sands, Holloman, NM	FPS-16

2. S - Band Antennas

Location	Description
Alamo Peak, WSMR, NM	7.3M, AZ-EL
Atom Peak, N Oscurra Pk, NM	7.3M, AZ-EL
Bermuda Island	9M, X-Y, N-S 9M, X-Y, E-W
Colorado Springs, CO	10M, AZ-EL
Diego Garcia	10M, AZ-EL
Dryden, DFRC, CA	4.3M, AZ-EL
Goldstone, CA	9M, X-Y, N-S 26M, X-Y, E-W
Jonathan Dickinson, FL	85ft, AZ-EL 50ft, AX-EL
Guam	18M, AZ-EL
Keana Point, HI	18M, AZ-EL
Madrid, Spain	26M, X-Y, E-W
Marritt Island, FL	9M, X-Y, N-S
Mt. Lemmon, AZ	4.3M, AZ-EL
New Boston, NH	14M, AZ-EL
Oak Hangar, UK	18M, AZ-EL
Point Pillar, CA	12M, AZ-EL
Ponce de Leon Inlet, FL	4M, AZ-EL
Seychelles, IOS	18M, AZ-EL
Tidbinbifla, Australia	26M, X-Y, E-W
Vandenberg AFB, CA	10M, AZ-EL 14M, AZ-EL
Wallops, VA	9M, X-Y, E-W

3. Optical Camera

Location	Description
Maui, HI	Camera
Santa Yenez Peak, CA	Camera
Tranquiflon Peak, CA	Camera

APPENDIX D: SURVEY QUESTIONNAIRE

Survey Questionnaire

9	8	7	6	5	4	3	2	1
EXTREMELY MORE IMPORTANT	STRONGLY MORE IMPORTANT	MODERATELY MORE IMPORTANT	SLIGHTLY MORE IMPORTANT	EQUALLY IMPORTANT	SLIGHTLY LESS IMPORTANT	MODERATELY LESS IMPORTANT	STRONGLY LESS IMPORTANT	EXTREMELY LESS IMPORTANT

Standardization is
____ than Flexibility.
____ than Capacity.
____ than Reliability
____ than Reporting & Tasking
____ than Information Timeliness
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Flexibility is
____ than Capacity
____ than Reliability
____ than Reporting & Tasking
____ than Information Timeliness
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Capacity is
____ than Reliability
____ than Reporting & Tasking
____ than Information Timeliness
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Survey Questionnaire

9	8	7	6	5	4	3	2	1
EXTREMELY MORE IMPORTANT	STRONGLY MORE IMPORTANT	MODERATELY MORE IMPORTANT	SLIGHTLY MORE IMPORTANT	EQUALLY IMPORTANT	SLIGHTLY LESS IMPORTANT	MODERATELY LESS IMPORTANT	STRONGLY LESS IMPORTANT	EXTREMELY LESS IMPORTANT

Reliability is
____ than Reporting & Tasking
____ than Information Timeliness
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Reporting & Tasking is
____ than Information Timeliness
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Information Timeliness is
____ than Training
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Training is
____ than Survivability
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Survivability is
____ than Relative Cost
____ than Technical Risk
____ than Maturity

Relative Cost is
____ than Technical Risk
____ than Maturity

Maturity is
____ than Technical Risk

1. Definition of Terms

a. Capacity

Capacity allows for the following: advanced capacity management planning ability; data rate easily variable to 25 Mbps based on user needs; and distributed open computing environments for easily expandable data processing capability.

b. Flexibility

Flexibility is a driver that takes into account automated mission planning and or scheduling; easily expandable and reconfigurable communications capability; secure system configurations to allow for operations across all classification levels; and lastly distributed open computing environments to allow rapid operational changes.

c. Information Timeliness

This driver is a measure of the architectures ability to satisfy all requirements levied on the space vehicle's control system by operational tasking in a timely manner.

d. Maturity

Maturity is a measure of the state of development of the proposed architecture. If the architecture is or has been operating in a fully operational mode then the candidate may be considered mature. If the candidate is based on technology under development and does not currently exist, then the architecture is in a concept state and cannot be considered mature.

e. Relative Cost

Relative cost is the cost to research the technical issues, develop, test and field the proposed TT&C architecture.

f. Reliability

That architecture which exhibits the following: expandable high data rate distributed workstations and broadened communications network; automated error detection and correction; and no mission impacting single point of failure.

g. Reporting & Tasking

Reporting and tasking takes into account the following: distributed open computing environment with interface to existing external standard command and control systems for near real-time reporting and current status updates based on operational requirements; and distributed open computing environment with interface to external standard command and control system for near real time tasking response based on operational requirements.

h. Standardization

The standardization of a TT&C architecture looks at the standard interfaces for all applications within the system and to all external users. The driver also takes into account minimum need for dedicated resources or payload specific configurations. Finally the driver takes into account for standard communications protocols and interfaces for voice, data, and video.

i. Survivability

This driver is a measure of an architectures capability to operate in a mobile and or transportable environment in support of warfighting missions. The driver also considers malicious attacks on the system by either conventional or informational methods.

j. Technical Risk

The technical risk is determined by evaluating the current state of technology versus the technology necessary to employ a proposed candidate architecture. The risk involved is the risk of developing the technology in the time frame necessary to support the employment of a new system.

k. Training

This driver allows for the direct connectivity between the space vehicle operations center and the space vehicle control simulation systems (training facilities).

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